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GEORGE OTIS SMITH, Director

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WATER-SUPPLY PAPER 397

GROUND WATER IN THE WATERBURY AREA CONNECTICUT

BY

ARTHUR J. ELLIS

Under the direction of HERBERT E. GREGORY

Prepared in cooperation with the
Connecticut State Geological and Natural History Survey

WASHINGTON
GOVERNMENT PRINTING OFFICE
1916

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CONTENTS.

	Page.
Introduction	7
Geology	9
Crystalline rocks	9
Glacial drift	10
Source and occurrence of ground water	10
Origin	10
Water in the glacial drift	11
Circulation	11
The water table	12
Amount of water	14
Water in crystalline rocks	17
Ground water for municipal use	17
Problems involved	17
Quantity required	18
Quality of water	19
Methods of obtaining water	20
Streams	20
Springs	21
Drilled wells	21
Dug wells	22
Infiltration galleries	23
Driven wells	23
Plant at Brookline, Mass	24
Plant at Brooklyn, N. Y	26
Plant at Plainfield, N. J	27
Ground waters for private use	29
Methods of developing ground-water supplies	31
Drilled wells	31
Construction	31
Cost	32
Quality of water	32
Improvements	33
Driven wells	33
Infiltration galleries	35
Dug wells	36
Descriptions of towns	39
Ansonia	39
Population and industries	39
Topography	39
Water-bearing formations	40
Surface-water supplies	40
Ground-water supplies	41
Public water supplies	41
Records of wells	42

Digitized by Google

Descriptions of towns—Continued. Page
Beacon Falls ... 4
Population and industries ... 4
Topography ... 4
Water-bearing formations ... 4
Surface-water supplies ... 4
Ground-water supplies ... 4
Public water supplies ... 4
Records of wells and springs ... 4
Middlebury ... 4
Population and industries ... 4
Topography ... 4
Water-bearing formations ... 47
Ground-water supplies ... 47
Records of wells and springs ... 47
Naugatuck ... 49
Population and industries ... 49
Topography ... 49
Water-bearing formations ... 49
Surface-water supplies ... 50
Ground-water supplies ... 50
Public water supplies ... 50
Records of wells ... 51
Oxford ... 51
Population and industries ... 51
Topography ... 52
Water-bearing formations ... 52
Surface-water supplies ... 53
Ground-water supplies ... 53
Records of wells and springs ... 54
Seymour ... 55
Population and industries ... 55
Topography ... 56
Water-bearing formations ... 56
Surface-water supplies ... 57
Ground-water supplies ... 57
Public water supplies ... 57
Records of wells and springs ... 58
Thomaston ... 59
Population and industries ... 59
Topography ... 60
Water-bearing formations ... 60
Surface-water supplies ... 60
Ground-water supplies ... 60
Public water supply ... 61
Records of wells ... 61
Waterbury ... 62
Population and industries ... 62
Topography ... 63
Water-bearing formations ... 63
Surface-water supplies ... 63
Ground-water supplies ... 63
Public water supply ... 64
Records of wells and springs ... 66

Digitized by Google

Descriptions of towns—Continued. Page.
Watertown 67
Population and industries 67
Topography 68
Water-bearing formations 68
Ground-water supplies 68
Public water supply 69
Records of wells and springs 70
Index 73

ILLUSTRATIONS.

Page.
PLATE I. *A*, Bowlder-strewn landscape in till-covered area, Ansonia, Conn.; *B*, Stratified beds of coarse sand, Ansonia, Conn. 10
II. *A*, Stratified sand and gravel, Naugatuck Valley, Seymour, Conn.; *B*, Crystalline rock (Hartland schist), showing fissures which at greater depths afford water supplies, Naugatuck, Conn. 18
III. Map of Waterbury area, Conn. ..... In pocket.
IV. Plan of property and detail of wells, water supply of Plainfield, N. J., 1891 34
FIGURE 1. Map of Connecticut, showing physiographic provinces, geologic formations, and areas covered by this and previous reports 8
2. Section across Naugatuck River valley below Waterbury, showing relation of bedrock surface to land surface 12
3. Diagrammatic section showing position and fluctuation of water table under various conditions 13
4. Section showing relation of water table to surface of ground 14
5, 6, 7. Diagrams showing possible artesian conditions in Connecticut 15, 16
8. Curves showing yield of drilled wells 30
9. Diagram of driven well 34
10. Sketch showing siphon well and domestic waterworks 38

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GROUND WATER IN THE WATERBURY AREA, CONNECTICUT.

By ARTHUR J. ELLIS.

INTRODUCTION.

The Waterbury area comprises a section of west-central Connecticut approximately 25 miles long, 7 miles wide, and 171 square miles in extent, reaching from Housatonic River northward to Thomaston and including the lower part of the Naugatuck Valley, its east and west borders coinciding approximately with the divides between the Naugatuck and other rivers. Within it are the towns of Ansonia, Seymour, Oxford, Beacon Falls, Naugatuck, Middlebury, Waterbury, Watertown, and Thomaston. (See fig. 1.)

Topographically the area consists of a troughlike valley with narrow floor, intersected by narrow valleys of streams tributary to the Naugatuck. At some places bare rock cliffs rise from the edges of the river to heights of more than a hundred feet; at other places, where tributaries enter, the lowlands are a mile or more in width. The lowest land, on Naugatuck River, where it crosses the south line of Ansonia, is only 18 feet above sea level; the highest, on Lattin Hill near the north boundary of Thomaston, is 1,022 feet above sea level.

Naugatuck River flows southward through the entire length of the Waterbury area, having a total fall within the area of about 400 feet. It receives a number of small but important streams between Thomaston and Ansonia, notably the West Branch of the Naugatuck, Mad River, Steel Brook, Long Meadow Pond Brook, Little River, and Bladens River. A small part of the drainage passes directly into Housatonic River above the mouth of the Naugatuck, and Eightmile Brook, which collects the drainage in the southwestern part of the area, is also tributary to the Housatonic.

The excellent water-power sites along the Naugatuck invited settlers into that valley very early in the history of the State, and the growth of industrial enterprises, although somewhat slow at first, has been very rapid during the last few decades. The manufacture of brass articles and general foundry work rank first among the industries, and in these as well as nearly all others water power has played an important part. But water is needed not only for power but for other industrial purposes as well as for municipal supplies,

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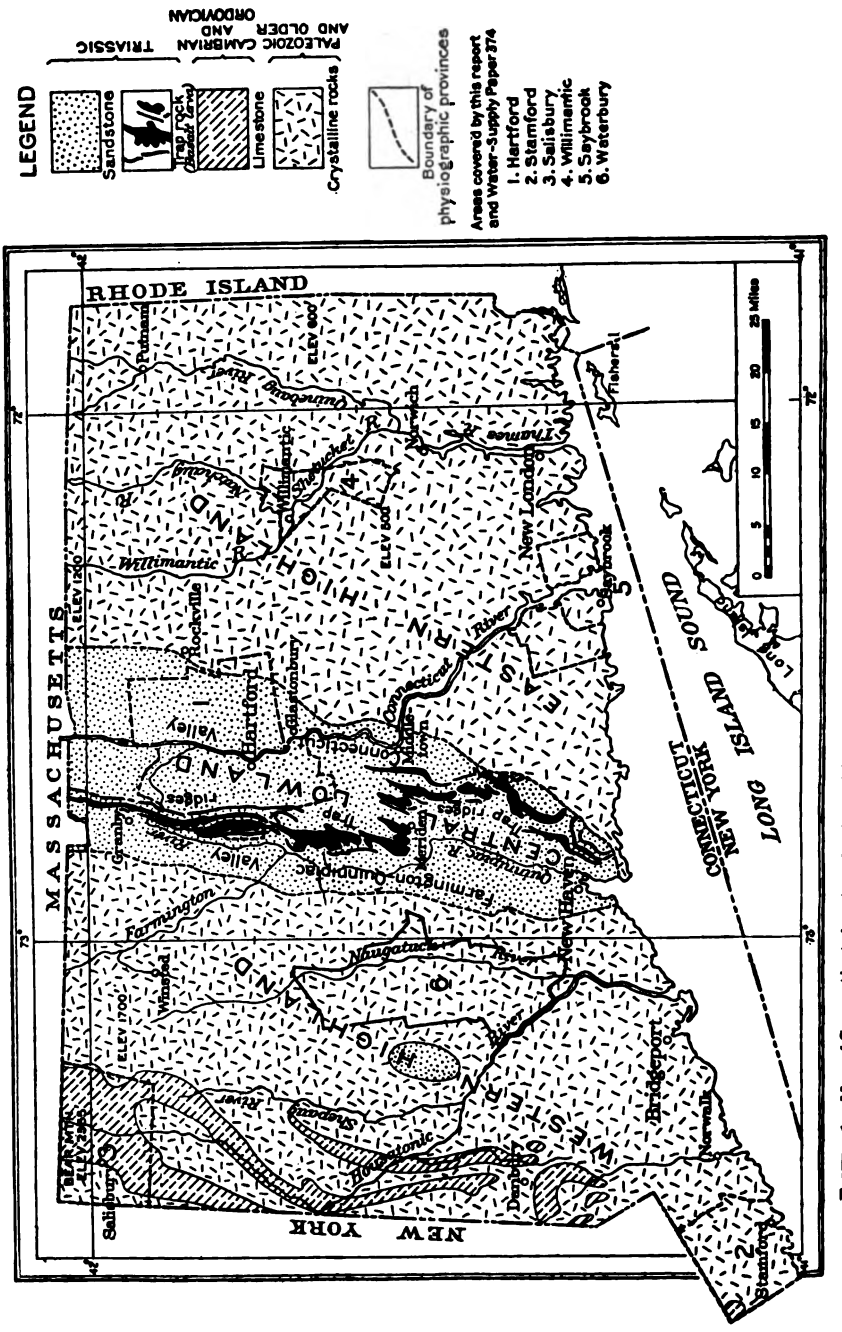

FIGURE 1.—Map of Connecticut showing physiographic provinces, geologic formations, and areas covered by this and previous reports.

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and with the increase and diversification of population and industries conflicts of interest have arisen—conflicts between water-power users and domestic consumers, between towns for the right to make use of a given stream or area; and between cities interested in sewage disposal and adjacent communities affected thereby. Industrial development inevitably taxes the natural water resources of a community, and although investigations of the local water problems may aid in formulating methods for conserving the use of water, it is necessary that State-wide regulations, following intelligent legislation, should be adopted to provide for the future.

GEOLOGY.

CRYSTALLINE ROCKS.

The area is underlain by crystalline rocks of undetermined age, which have been classified according to lithologic characteristics into the formations [1] described in the following paragraphs:

1. *Orange phyllite.*—This rock is a slate or phyllite, highly fissile, sericitic, and usually dotted with minute garnets. It is characterized by many quartz veins and lenses of quartz. It is believed to have been originally a more or less calcareous shale.

2. *Thomaston granite gneiss.*—This rock varies in structure from an almost massive granite to a rock with distinctly schistose phases. It is of igneous origin, as shown by the fact that it often occurs as dikes and includes fragments of other rocks.

3. *Hoosac ("Hartland") schist.*—This formation is everywhere a mica schist of well-marked character, but exhibits great variation in texture, composition, and appearance, due to large intrusions of igneous rock. It is of sedimentary origin. The "Hartland" schist of Connecticut has been traced into the Hoosac schist of Massachusetts, and the name "Hartland" has been abandoned by the United States Geological Survey in favor of the older name Hoosac. The Hoosac schist is regarded as of Ordovician age.

4. *Waterbury gneiss.*—This gneiss was doubtless originally Hoosac ("Hartland") schist, whose texture has been changed by granitic intrusions and quartzose veins.

5. *Prospect granite gneiss.*—This is a light-gray granitic rock whose gneissoid appearance is produced by bands of granular quartz and feldspar interbedded with layers composed chiefly of biotite. The porphyritic mineral is usually white or pink orthoclase in crystals ranging in length from one-sixteenth inch to 3 inches. The rock was probably a granite porphyry intruded into the Hoosac schist.

[1] Rice, W. N., and Gregory, H. E., Manual of the geology of Connecticut: Connecticut State Geol. and Nat. Hist. Survey Bull. 6, pp. 96–110, 1906. Gregory, H. E., and Robinson, H. H., Preliminary geologic map of Connecticut: Connecticut State Geol. and Nat. Hist. Survey Bull. 7, pp. 33, 34, and map, 1907.

The retention in this economic report of the geologic names used in the reports published by the State does not imply their adoption by the United States Geological Survey, and all are subject to revision, except Hoosac schist, which has been adopted.

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6. *Amphibolite.*—This rock is distinctly gneissoid in structure, and is composed in large part of porphyritic feldspar and green hornblende, with a subordinate amount of quartz.

7. *Diabase.*—This rock is a colored trap occurring as dikes intruded into the older crystalline rocks. It is probably of Triassic age.

GLACIAL DRIFT.

The crystalline rocks are covered by deposits of glacial drift derived from the great ice sheets which in the Pleistocene epoch extended over the State. They are of two general types: The unstratified drift, also called "till," which consists of heterogeneous mixtures of all the rock débris deposited directly by the ice; and the stratified drift, which consists of glacial materials that were rehandled by water and are therefore assorted into layers of different degrees of coarseness. Till constitutes the surface deposits over most of the highland areas, and stratified drift is found chiefly in the stream valleys.

SOURCE AND OCCURRENCE OF GROUND WATER.

ORIGIN.

The ground water of the Waterbury area is derived from the precipitation within the area and near its borders. Owing to the ruggedness of the bedrock surface and the thinness of the overlying drift, which together prevent an extensive underground circulation, the ground water of any particular locality is derived from very local sources.

Owing to the small size of the area, the precipitation is evenly distributed, and, as shown in the following table, is nearly uniform throughout the year.

Rainfall in Waterbury from 1887 to 1912, inclusive.[a]

[Recorded by N. J. Walton.]

Year.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Total.
1887	4.75	6.07	4.24	3.94	0.13	6.60	3.79	5.64	1.68	2.97	2.25	5.20	47.26
1888	4.73	5.11	6.46	1.78	4.13	1.55	2.73	4.53	7.57	4.72	4.42	5.84	53.57
1889	5.85	1.61	2.02	4.29	4.64	4.09	10.83	2.76	4.26	4.03	8.74	2.74	55.86
1890	2.54	3.77	6.08	2.43	5.97	3.26	4.96	4.50	4.98	6.89	0.93	5.21	51.52
1891	10.06	5.65	5.08	3.86	1.84	1.14	4.17	3.04	1.68	3.04	3.33	5.71	48.60
1892	6.01	1.30	3.45	.95	5.55	2.27	4.37	5.30	2.62	.92	5.96	1.74	40.44
1893	2.96	7.37	4.83	3.49	6.44	1.82	3.31	7.22	1.75	5.21	2.49	4.08	50.97
1894	2.68	4.13	1.43	3.16	7.58	.54	2.43	2.41	5.35	4.91	4.30	4.21	43.13
1895	4.86	1.92	2.58	3.85	1.96	2.82	3.73	7.29	2.16	5.19	5.22	3.83	45.41
1896	2.37	9.25	5.99	1.83	2.34	5.71	3.16	2.67	5.01	2.77	3.09	2.39	46.58
1897	4.58	3.48	2.67	1.97	5.34	3.77	18.10	3.51	2.18	1.08	6.00	5.99	58.67
1898	5.09	3.49	2.47	3.67	6.86	.94	3.37	9.48	2.52	5.82	7.57	3.86	55.14
1899	3.82	4.58	6.75	1.80	2.07	2.32	6.02	1.03	5.30	2.42	1.69	2.81	40.61
1900	3.77	8.46	5.51	2.23	4.39	3.02	3.10	2.09	2.15	3.59	5.96	2.56	46.83
1901	1.78	.55	7.44	11.51	8.08	.65	4.44	9.37	6.25	4.32	2.37	9.82	66.58
1902	3.43	6.67	5.56	4.11	2.01	5.16	4.58	2.82	6.42	6.19	1.34	6.92	55.21
1903	3.78	4.32	6.45	3.38	.73	11.25	3.71	6.36	3.02	4.77	2.30	4.37	54.44
1904	4.45	2.54	3.74	4.50	3.31	4.20	4.62	4.93	8.02	3.05	1.59	3.28	48.23
1905	6.51	1.50	3.59	2.85	1.27	4.22	4.20	5.65	4.27	2.50	1.72	3.72	42.00
1906	2.79	2.29	5.97	4.30	3.74	4.83	5.49	2.71	1.92	6.26	2.18	4.13	46.61
1907	3.45	2.52	1.53	2.77	3.87	4.37	2.29	1.35	9.82	5.89	5.69	5.81	49.36
1908	4.72	6.86	3.07	2.65	5.85	1.10	6.53	6.53	1.39	2.43	1.14	3.75	46.02
1909	3.83	6.15	4.36	7.97	2.83	3.11	1.56	3.47	4.51	1.17	1.89	4.83	45.68
1910	8.05	4.27	1.16	4.08	2.95	3.30	3.04	3.16	2.56	.98	5.40	2.21	41.16
1911	2.99	2.81	3.69	3.75	.87	3.33	4.54	8.11	2.24	8.27	4.48	3.44	48.52
1912	2.36	3.20	7.87	4.38	5.51	.91	3.63	3.12	2.34	3.52	3.97	4.64	45.45
Average	4.31	4.23	4.38	3.67	3.86	3.32	4.72	4.58	3.92	3.96	3.69	4.35	48.99

[a] From Waterbury City Engineer's Ann. Rept., 1912.

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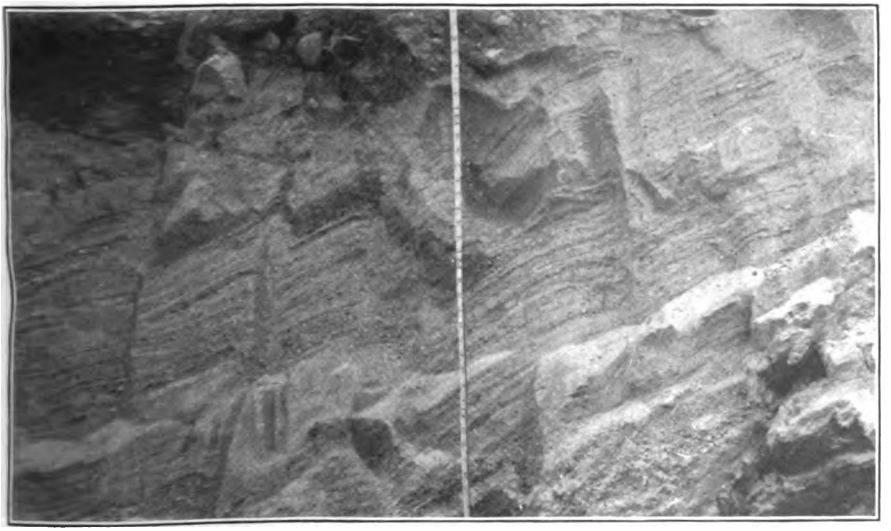
A. BOWLDER-STREWN LANDSCAPE IN TILL-COVERED AREA, ANSONIA, CONN.



B. STRATIFIED BEDS OF COARSE SAND, ANSONIA, CONN.

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WATER IN THE GLACIAL DRIFT.

CIRCULATION.

The chief water-bearing formations of the Waterbury area are the unconsolidated materials that cover the bedrock. These materials absorb rain water at a rate and to an extent depending chiefly on their porosity. The most porous beds are composed of gravel and sand, the least porous of compact clays. The unstratified drift, which covers most of the area, is a mixture of bowlders, gravel, sand, and clay, and its porosity depends on the relative amounts of these materials. (See Pl. I.) Much of the unstratified drift is of the "stony" or "bowldery" type, which contains practically no clay and which possesses a porosity equal to that attained by coarse varieties of stratified drift. The less porous types of unstratified drift may be represented by the following averages of the analyses of 16 samples collected from 12 drumlins in the Boston basin.[1] These analyses were made after removing all stones 2 inches or more in diameter, which constituted about 10 per cent of the original material.

Average composition of unstratified drift in Boston basin.

	Per cent.
Gravel	24.90
Sand	19.51
Rock flour	43.86
Clay (three-fourths rock flour)	11.67
	99.94

Other factors influencing the amount of water absorbed are the growth of vegetation, the topography, the occurrence and duration of frost in the ground, and the atmospheric conditions that govern evaporation and rates of precipitation.

The water absorbed by the soil descends and saturates the lower part of the glacial drift, which serves as a reservoir for the storage of this water. The efficiency of the drift in this respect depends largely on the rate of underground drainage, the three principal factors of which are porosity, the arrangement of layers having different porosities, and the topography of the bedrock on which the water-bearing bed rests. The most porous beds, such as the gravels of the Naugatuck River valley (Pl. III, in pocket), absorb water most rapidly, but they also allow the water to circulate most freely and therefore are most rapidly drained. Impervious materials, such as clays, occurring among porous deposits are related to underground drainage as dams or other obstructions are related to surface drainage. They divert or impound the percolating waters and in many places produce springs and swamps. Except where the drift is thick, the topography of the bedrock below the water-bearing beds

[1] Crosby, W. O., Composition of till or bowlder clay: Boston Soc. Nat. Hist. Proc., vol. 25, p. 124, 1890.

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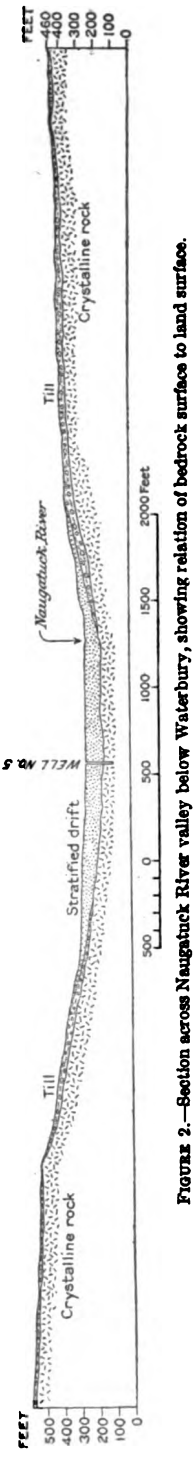

FIGURE 2.—Section across Naugatuck River valley below Waterbury, showing relation of bedrock surface to land surface.

is related to underground drainage as the topography of the land is related to surface drainage. Over most of the Waterbury area the drift is thin and the topography of the bedrock surface closely conforms to the present topography of the land surface, except that it is more rugged and has greater relief. The bedrock usually outcrops on the hilltops and steep slopes (Pl. III) but lies at considerable depths in some of the valleys, for example, in the Naugatuck Valley near Waterbury, where bedrock is reached at a depth of more than 100 feet below the river (fig. 2). Because of the similarity between the forms of the rock surface and the surface of the ground the direction of underground drainage corresponds very closely to the direction of surface drainage. The ground water, like the surface water, flows most rapidly on steep slopes, but because of the resistance offered by the soil particles it moves much more slowly than the surface water and is generally replenished by rainfall before the supply contributed by previous precipitation has been drained away. Most of the ground water finds its way to the surface through the flow of springs and seepage areas, by capillary rise and evaporation, and by transpiration of trees and other plants; a comparatively small amount is drawn from wells.

THE WATER TABLE.

The water table is the plane below which the ground is saturated with water. Its topography is similar to that of the land surface but less rugged. Consequently it is generally nearest the land surface in the valleys and farthest from the surface on the hilltops, where it may lie at a depth of 30 or 40 feet. The surfaces of streams, ponds, and lakes are generally continuous with the water table and may be regarded as forming parts of it. In bogs, marshes, and other places where the ground is saturated to the surface, the water table and the surface of the ground coincide. Where the water table is not exposed its position is shown by the surface of the water in wells. The position of the water table depends also on the character of the drift. Except in very low places it is, in general, nearer the surface in areas where the drift consists of clay

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or compact till, and farther below the surface in areas where the drift is gravel and sand, because clay and till are less porous than gravel and sand and do not drain as rapidly.

The accompanying map (Pl. III, in pocket) shows the average depth to the water table at the wells that were examined. Where dense rocks appear at or near the surface there is no water table; the rock masses rise above the ground water like islands in a lake, and the position of the water table immediately surrounding them is indeterminate. Figure 3 illustrates the relative position of the water table in various kinds of drift and under different topographic conditions.

The water table is constantly changing its position with respect to the surface of the ground, rising rapidly after a heavy rain, then gradually descending as the water is drained away. These changes may be observed by making successive measurements of the depths to water in wells. The zone through which the water table fluctuates is called in this report the zone of fluctuation.

In elevated positions where the drift is thin the water table may descend during a period of drought until it touches the rock surface and is all drained away; but in the vicinity of perennial streams or permanent bodies of water the change may not exceed a few inches during a year. The zone of fluctuation, therefore, has the least thickness in the valleys and the greatest on the hills, where it may include the entire distance from the highest water level to the bedrock surface.

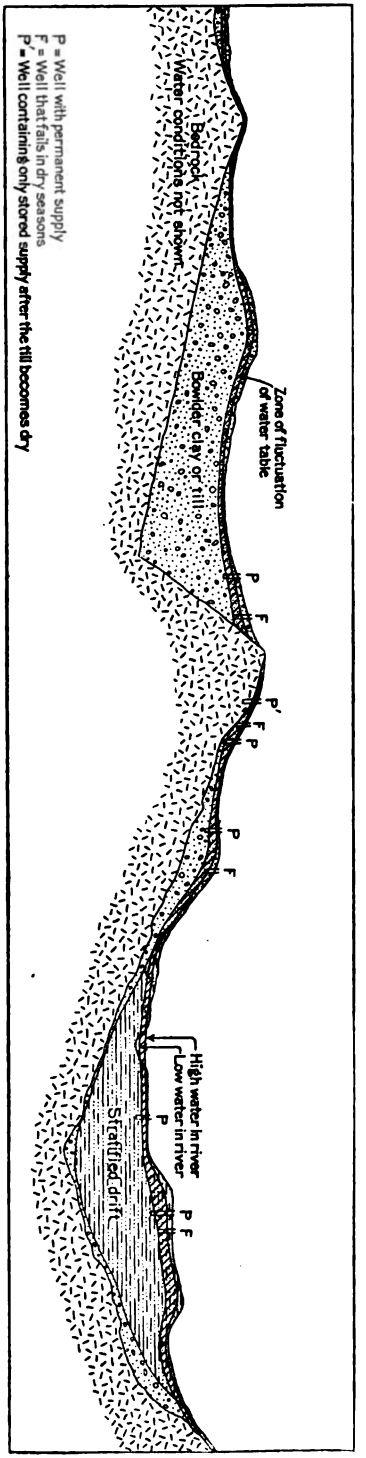

FIGURE 3.—Diagrammatic section showing position and fluctuation of water table under various conditions.

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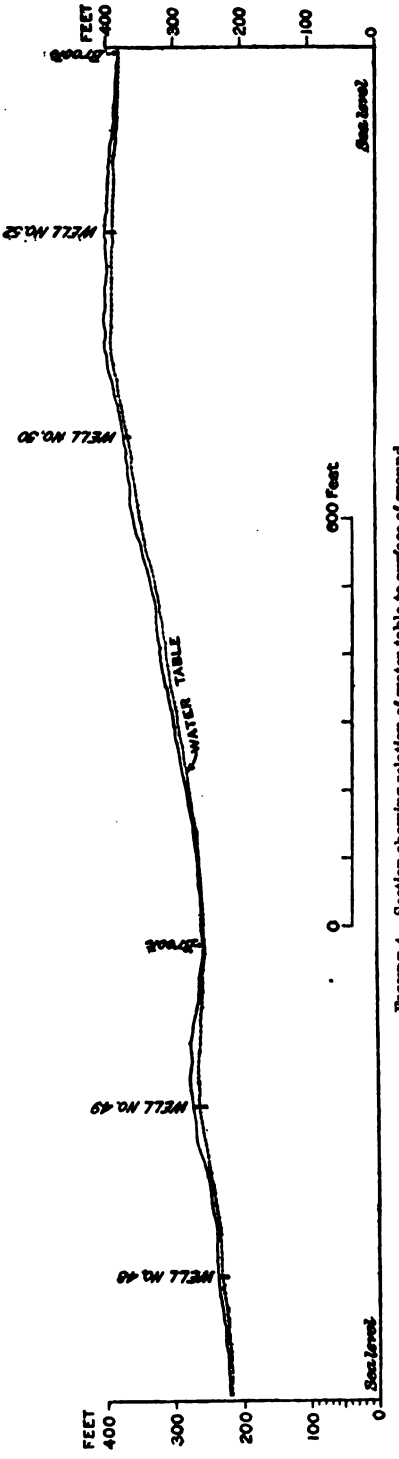

FIGURE 4.—Section showing relation of water table to surface of ground.

AMOUNT OF WATER.

A rough conception of the annual supply of ground water may be gained by analyzing the relations between precipitation and stream flow. Measurements of precipitation show the total amount of water which falls on a drainage basin, but only a part of this is added to the underground supply, a part of the rest being returned to the atmosphere, and another part discharged by streams. The total run-off from a drainage basin, as determined by stream measurements, includes both the surface drainage (that is, the water which has never formed part of the underground supply) and the underground drainage—the water which has passed into the surface streams from the water-bearing beds.

The water that is returned to the atmosphere by evaporation and transpiration is in part surface water and in part ground water. A rough index of its amount is obtained by subtracting the total annual run-off from the total annual precipitation. In the Housatonic River basin above Gaylordsville, Conn. (area, 1,020 square miles), the annual rainfall is 47.86 inches and the mean annual run-off is 29.43 inches. The difference of 18.43 inches is attributed to loss by evaporation and plant growth. Similarly, in Connecticut River basin above Orford, N. H. (area, 3,300 square miles), the annual precipitation is 36.76 inches and the annual run-off is 21.66 inches, the loss being 15.10 inches.

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These and other data compiled by Mr. Hoyt[1] indicate that in northeastern United States between 30 and 40 per cent of the rainfall is returned to the atmosphere. It is not possible to determine, from

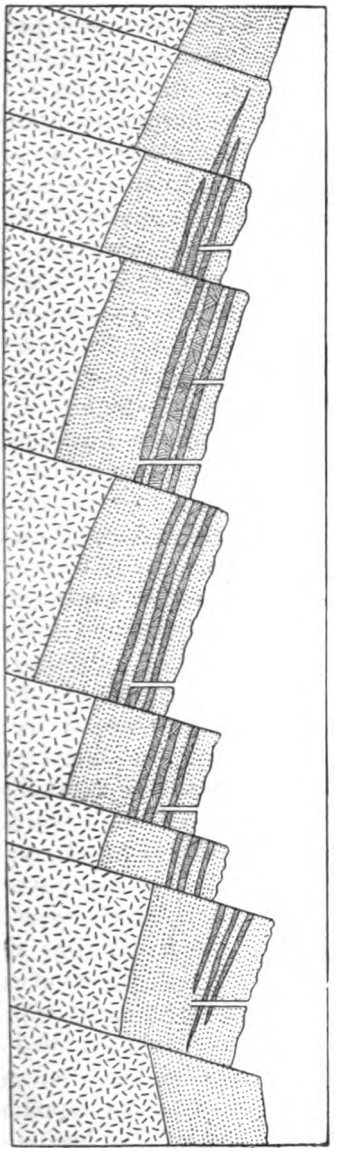

FIGURE 6.—Diagram showing possible artesian conditions in Connecticut.

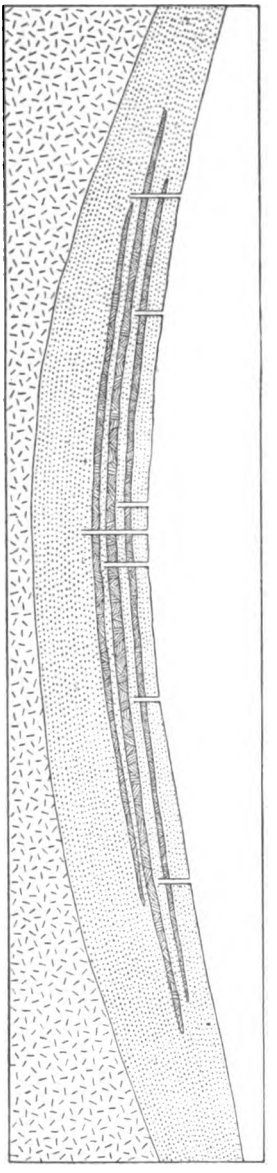

FIGURE 5.—Diagram showing possible artesian conditions in Connecticut.

the data at hand, what part of this is derived from the underground supply. All perennial streams lie below the water table and are maintained during dry seasons by infiltration from the saturated part

[1] Hoyt, J. C., Comparison between rainfall and run-off in northeastern United States: Am. Soc. Civil Eng. Trans., vol. 59, p. 470, 1907.

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of the drift. During a rainy season and for some time thereafter the streams carry more or less water which has never formed a part of the ground-water supply. During the succeeding dry season this surface water is discharged and the streams finally reach a stage at which nearly the entire run-off is water from underground sources. In Connecticut the discharge of underground water is never less than the amount carried by the streams at their lowest stages, but it is probably greater immediately after rains, owing to the contribution from intermittent springs and seepage areas and to a general acceleration of underground circulation by hydrostatic pressure. In addition to the amount of ground water discharged by streams there are large quantities stored in drift-filled rock basins below the valley floors, as for example in the valley of Naugatuck River near Waterbury, where saturated deposits consisting largely of gravel and sand extend nearly 100 feet below the river bed (fig. 2). The amount of water in such basins depends on the size of the basins and the porosity of the valley fill. But the water contained in such basins, if withdrawn, must be replenished by that usually carried in the streams, therefore, strictly speaking, these supplies are not available

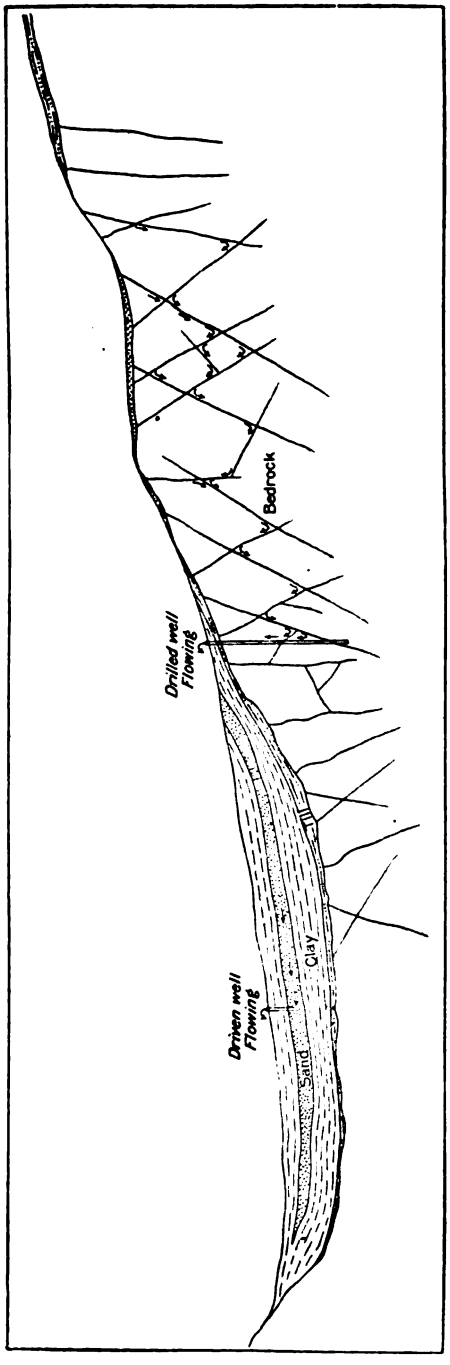

FIGURE 7.—Diagram showing possible artesian conditions in Connecticut.

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in addition to the amounts discharged by streams, except as their withdrawal would decrease the amount of evaporation and transpiration.

WATER IN CRYSTALLINE ROCKS.

The area described in this report is underlain by crystalline rocks whose age has not been definitely determined (p. 9). As a result of the work of dynamic agencies these rocks are intensely fractured, cracks being visible wherever the rocks are exposed (Pl. II, *B*). All the crystalline rocks have a very low porosity—less than 1 per cent—and for this reason the circulation of water in them is practically restricted to the cracks. Water enters the openings from the overlying drift and passes in the direction of least resistance, down some sloping planes and up others, through vertical cracks and horizontally through level ones until it becomes imprisoned in cracks with no outlets or until it reappears at the surface as springs or seepage.

In general, the thickness of the zone of active circulation is nearly equal to the relief of the land surface. That is, openings below the level of the valleys are generally filled with water that is not in motion until wells reach these depths and start circulation by drawing water to the surface. In some places, however, these more deeply seated waters are forced by hydrostatic pressure along fault planes or major joints and reach the surface as artesian springs or artesian wells. (See figs. 5, 6, and 7.)

The amount of water in crystalline rocks depends chiefly on the number and size of the cracks. Most of the openings are too narrow, even at the surface, to allow any considerable quantity of water to pass, but they are generally connected, either directly or indirectly, with larger fissures into which they drain, and it is the ramifying systems of minor cracks which to a large degree regulate the supplies derived from rock borings. The openings in these rocks do not extend to great depths and their size rapidly diminishes from the surface downward. Nearly all the cracks pinch out entirely within a few hundred feet from the surface, and water-bearing fissures at greater depths are rare. As compared with the more porous drift, crystalline rocks contain little water, the average yield of wells in the crystallines of Connecticut being about 15 gallons a minute. Many deep rock wells in the State are practically dry, but a number of others obtain water from joints and cracks within 100 feet of the surface.

GROUND WATER FOR MUNICIPAL USE.

PROBLEMS INVOLVED.

The problems to be considered in planning the use of ground water for a new or enlarged public water supply relate to the quantity of water to be obtained, the quality of the water, the methods of pro-

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curing it, and the cost of establishing and maintaining the works. These problems are largely interdependent and their relative importance depends on the proposed uses of the water and the conditions under which it is to be used.

QUANTITY REQUIRED.

In towns with an established water system the per capita consumption is known and the quantity of water required for extending the system can be estimated with a fair degree of accuracy. In small towns or communities in which a public supply is designed to replace private wells an estimate of the quantity of water required should be based on a comparative study of the consumption in towns of similar characteristics. Plans for cities or for smaller communities involve a consideration of future needs based on the probable rate of increase in population and the circumstances affecting it and also on the estimated rate and amount of development of industrial enterprises. In a community where the significance of past conditions and present trends of population and industries are fairly well understood, plans for a 20-year service for an average town of less than 10,000 may be based on the present population. For larger cities estimates of future needs are much less likely to be reliable, and so far as practicable future requirements should be provided for by maintaining a system capable of extension at reasonable cost as the need arises. The data available for the larger cities of Connecticut are sufficient to serve as a guide in planning ten years in advance of present needs, on the basis of an estimated consumption of 100 gallons per capita per day.

The factors which determine the amount of water required are as follows:

1. The number of inhabitants.
2. The nature of the local industries.
3. The wealth and habits of the people.
4. The extent to which water is used in fountains and in lawn and street sprinkling.
5. The climate as affecting the use and waste of water to prevent freezing.
6. The prevention of leakage.
7. The basis of revenue (meter or flat rate).
8. Quality, quantity, and pressure, as tending to encourage or discourage liberal use and great wastefulness.
9. The popularity of a new or improved supply.

The consumption of water is usually stated in number of gallons per capita per day, but it is not sufficient to take into account only this average daily rate of consumption, for the demand varies during the year and during the day, and the supply must be adequate for temporary heavy draughts. The following table shows the average daily consumption in Hartford, Conn., for each month during 1912 and during the period from 1903 to 1912, inclusive:

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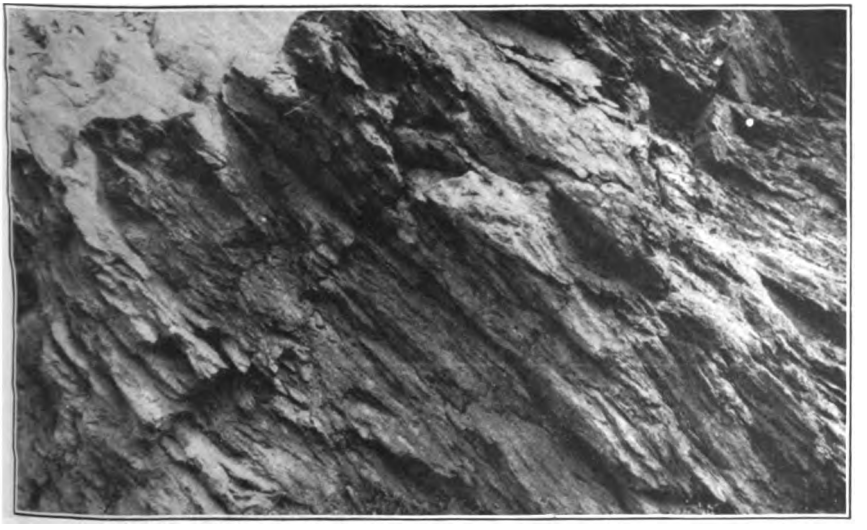
A. STRATIFIED SAND AND GRAVEL, NAUGATUCK VALLEY, SEYMOUR, CONN.



B. CRYSTALLINE ROCK (HARTLAND SCHIST) SHOWING FISSURES WHICH AT GREATER DEPTHS AFFORD WATER SUPPLIES, NAUGATUCK, CONN.

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Average daily consumption of water during each month in Hartford, Conn.[a]

Month.	1912.	Average for 10 years (1903–1912).	Month.	1912.	Average for 10 years (1903–1912).
	Gallons.	*Gallons.*		*Gallons.*	*Gallons.*
January	8,317,000	6,717,000	July	9,245,000	7,642,000
February	8,730,000	6,959,000	August	8,694,000	7,315,000
March	8,625,000	6,806,000	September	8,675,000	7,411,000
April	8,445,000	7,044,000	October	8,674,000	7,191,000
May	8,800,000	7,380,000	November	8,283,000	6,978,000
June	9,128,000	7,648,000	December	8,142,000	6,775,000

[a] Board of Water Commissioners, City of Hartford, Conn., Fifty-ninth Ann. Rept., for year ending Mar. 1, 1913, p. 190.

The following table illustrates the variation in the rate of consumption during the day:[1]

Consumption from the Mystic supply of Boston, Mass., August, 1893.

Hours.	Rate of consumption per capita (gallons per 24 hours).	Per cent of total consumption.
1 to 4 a. m.	[a] 40.8	6.9
4 to 7 a. m.	58.6	9.9
7 to 10 a. m.	103.8	17.6
10 a. m. to 1 p. m.	93.0	15.8
1 to 4 p. m.	98.2	16.8
4 to 7 p. m.	79.5	13.6
7 to 10 p. m.	61.9	10.5
10 p. m. to 1 a. m.	52.9	8.9
Average	73.6	100.0

[a] "The large consumption from 1 to 4 a. m. must have been mostly waste."

To meet these daily peak loads and to insure against such emergencies as might arise from fire or disability of pumps a ground-water supply system should be equipped with a surface reservoir or elevated tank unless the capacity of the pumps and wells is much greater than the normal consumption.

QUALITY OF WATER.

A municipal water supply should be suitable in quality for both domestic and industrial uses. To meet these requirements the installation of purifying equipment may be necessary, whether the supply comes from surface or underground sources. Surface waters are always liable to pollution, and contamination of some is practically inevitable. The mineral content and hardness of most surface waters are not such as to render them unfit for general use, but ground waters, especially ground waters drawn from the bedrocks, may require softening or at least the removal of iron before the waters are usable. Ground waters are less liable to pollution than surface waters, but they are more strongly mineralized and may be mineralized to an objectionable degree.

[1] Turneaure, F. E., and Russell, H. L., Public water supplies, p. 29, 1908.

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METHODS OF OBTAINING WATER.

The method of collecting water for a municipal supply depends on the natural conditions existing in the locality where water is needed. The possible sources to be considered are streams, springs, deep wells, filtration galleries, and shallow wells.

The extent to which each of these methods is employed in New England is shown in the following table:

Sources of water in public water supplies in New England.[a]

State.	Number of public supplies derived from—										
	Surface water.[b]	Surface water and springs.	Surface water and shallow wells.	Springs	Shallow wells.		Shallow wells and springs.	Galleries.	Shallow wells and galleries.	Deep and artesian wells.	Total.
					Dug.	Driven.					
Maine	53	2	0	12	1	0	0	0	0	2	70
New Hampshire	37	2	0	17	1	2	0	0	0	2	61
Vermont	21	3	0	13	0	0	0	0	0	0	37
Massachusetts	67	2	3	23	20	14	3	6	4	1	143
Rhode Island	12	0	0	0	1	0	0	0	0	0	13
Connecticut	48	9	0	8	0	0	0	0	0	2	67
	238	18	3	73	23	16	3	6	4	7	391

[a] Compiled from Baker, M. N., Manual of American waterworks, 1897.
[b] Surface water includes supplies from streams, lakes, and impounding reservoirs.

STREAMS.

Streams generally afford the simplest means of obtaining water. If the minimum daily discharge of the available stream exceeds the maximum daily consumption by an amount sufficient to provide for fire protection, the water may be diverted directly into the street mains; if, however, the daily discharge as determined by measurements extending through a number of years is not sufficient to meet the daily consumption and afford fire protection, storage must be provided. Since large streams are generally utilized in the disposal of sewage, it is the custom to go to the smaller ones for water supplies, hence the most common type of development involves the construction of reservoirs. A useful rule for estimating the required storage is that the amount stored shall be about the same percentage of the total yearly consumption as the total yearly consumption is of the total yield of the drainage basin.[1]

Practically all the available ground water of the drift, except that stored in the deposits below Naugatuck River, and a considerable amount from crevices in the bedrocks returns to the surface along the stream courses. For this reason the most effective method of

[1] International Library of Technology, vol. 36, Water supply, pp. 1, 322.

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recovering this ground water is by constructing dams in the streams that carry it. Ground water is thus brought to the surface without pumping and if a reservoir is available from which water can be delivered by gravity the cost of pumping may be eliminated entirely.

SPRINGS.

Springs may be grouped into two classes, the first including those which serve as outlets for ground waters that have reached horizons far below the earth's surface, and the second comprising those which derive their supply from ground waters that have passed to shallow depths only.

So far as known all the springs in this area belong to the second class. They are numerous along nearly all the streams, which owe their persistence through dry seasons to water from this source. Most springs of this kind are small. They vary in yield with the amount and character of local precipitation, and their permanence depends on the seasonal distribution of rainfall, the areas of their individual collecting basins, and the nature of the soil and vegetation. Most of the small, so-called surface-water supplies in the State are supported to a large extent by springs of this type, but, because of their liability to fail in dry seasons and their average low yield these springs are not adapted for use as public supplies, unless they occur close together and in localities where the surplus yield during wet seasons may be stored for use in droughts. A sufficient number of springs in a favorable locality would result in either a lake or a stream. The accumulated waters from such groups of springs would possess the qualities of surface-water supplies and would properly be classed with them.

Most deep-seated springs are independent of seasonal changes and are free from surface pollution. They may, however, contain sufficient mineral matter to render them undesirable for a municipal supply or desirable for medicinal use. Springs of this type in other parts of Connecticut furnish waters of high purity and are widely exploited. Their commercial value as bottled waters, as well as their moderate yields, will doubtless continue to prevent their use as parts of public water systems.

DRILLED WELLS.

The often-expressed idea that a well of water, or even a flowing well, may be obtained anywhere by drilling deep enough is based on an erroneous conception of the occurrence of ground water. Some artesian areas, as, for example, those of Texas and South Dakota, are underlain by extensive beds of porous water-bearing rocks capable of furnishing large and continuous supplies. In such districts it is

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usually possible, after a few wells have been drilled, to predict with considerable accuracy the depth at which water will be found and the quantity that will be obtained. In areas underlain by such materials as those forming the rock floor of this area, however, large supplies are seldom obtained by drilling into the bedrock. Moreover, the yields of new wells can not be predicted from the records of existing rock wells because the supplies are obtained from discontinuous and irregular fissures which vary in size, distribution, and water content.

Wells that overflow at the surface are not common in Connecticut, but in some places flowing water has been obtained both by drilling into bedrock and by driving "points" to shallow depths in the drift. Where flows have been struck the head is generally low and the flow often ceases within a few days or even within a few hours. In drilled wells the flow is due to conditions illustrated in figures 5, 6, and 7. If a sloping rock surface is covered by an impervious stratum of clay or till such a stratum may confine the water in the rock crevices and generate hydrostatic pressure that forces the water to the surface when a well penetrates the impervious stratum. In some shallow wells the conditions are similar. A sloping stratum of sand or gravel confined between beds of clay may contain water under sufficient pressure to afford a flowing well when the upper impervious layer is penetrated by a driven point.

Conditions favorable for producing flowing wells are seldom encountered, and ground waters must therefore generally be recovered by pumping. Moreover, in most drilled wells the water does not rise to a level within the suction limit, and a gang of drilled wells can therefore generally not be pumped by means of a suction main, and a lift pump is required in each well except where air lifts can be used to advantage. On account of the small yields, high costs, and great uncertainty in regard to every phase of the development, drilled wells are hardly to be considered for supplying large municipalities. For villages in which the consumption does not exceed 50,000 gallons a day and where surface-water supplies are not easily available satisfactory supplies may be obtained by drilling one or more wells into rock.

DUG WELLS.

Dug wells draw their supplies from the glacial drift. They are best adapted to areas in which the drift is not very porous and yields water slowly, whereas driven wells are best adapted for areas in valleys in which deposits of porous stratified drift supply water more freely. The yield from a dug well depends on the porosity of the drift, the dimensions of the well, and the depth of the well below the water table. To obtain permanent supplies these wells must pass below the lowest position of the water table. Dug wells are not

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adapted for furnishing public supplies unless the amount of water required is small, and even then such a supply would hardly justify the installation of the necessary pumps and pipe lines because the cost would be great for each unit of water developed.

INFILTRATION GALLERIES.

Underground galleries or tunnels are usually constructed for the purpose of filtering stream waters. Under favorable conditions they may be used to recover ground water, but in general wherever the deposits are porous enough to yield much water to infiltration galleries, water can be obtained more economically and satisfactorily by means of driven wells. Infiltration galleries are expensive to construct and are subject to decreases in efficiency which are not easily remedied. It is probable that in this area driven wells will be found to possess a number of advantages over infiltration galleries. (See p. 35.)

DRIVEN WELLS.

The Naugatuck River valley contains deposits of coarse sediments which are capable of yielding large quantities of water, provided the recharge is adequate. The valley is narrow, however, and most of the coarse deposits rest on the valley walls (Pl. III), where they are rapidly drained and are consequently of no importance as a source of water even for domestic use. Furthermore, the valley is constricted in places and at such points the underflow is interrupted. In some parts of the valley, however, the coarse deposits below the river are sufficiently broad and deep to afford storage of large quantities of water. Driven wells with perforated iron casings 6 or 8 inches in diameter, as described on page 33, probably afford the most economical method of obtaining water from this source. A project involving the use of driven wells differs from one in which drilled rock wells are to be used in that reliable information regarding the quantity and quality of water available can be obtained at moderate cost. The thickness and extent of the water-bearing formation can be determined by rough surveys, and pumping tests by means of drive points will establish the feasibility of proceeding with the project. It seems improbable, considering the availability of surface water, that ground water could be economically used as a source of supply by a city as large as Waterbury, but it is certain that many communities, such as the villages of Beacon Falls, Thomaston, and possibly Seymour, requiring moderate amounts of water, could obtain supplies of this kind, and the cities of Waterbury, Ansonia, and Naugatuck could obtain supplementary supplies in this manner if demand should arise.

The use of driven wells is illustrated by the following plants at Brookline, Mass., Brooklyn, N. Y., and Plainfield, N. J.:

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Plant at Brookline, Mass.—The following description of the municipal pumping plant at Brookline, Mass., was given by Mr. F. F. Forbes, the superintendent:[1]

The material for this paper was gathered from work which was done under my direction in Brookline, two and four years ago, to increase the water supply of this town.

The work consisted in laying a suction main made up as follows: 2,054 feet of 24-inch pipe, 2,093 feet of 20-inch pipe, 531 feet of 16-inch pipe, 1,427 feet of 10-inch pipe, and 155 feet of 8-inch pipe, a total of 6,260 feet; and driving 201 2½-inch wells, and connecting 160 wells; the other 41 wells were failures.

The plant was designed to deliver water at the rate of 5,000,000 gallons per day for as many hours each day as might be necessary to supply the town. A slight study of such a plant will convince one that it is very important that the pipes and connections should be air-tight, and so put together that they will remain in this state even if some small settling should take place in the suction main; for not only does it cost money to pump air from which no benefit is received, but its presence in the conducting pipes lessens the amount of water they will carry, also decreases the quantity which can be taken from the ground by partially destroying the vacuum and also causes the pumps to perform badly unless the air is removed before it reaches them.

It is not an easy matter to lay a long line of pipe, drive and connect numerous wells, and leave no place through which the air can flow. Not only must the material used be without defects, but the work must be most faithfully done—the latter being by far the most difficult part. It is with much satisfaction that I can speak of the results obtained in Brookline. The plant has now been in use nearly two years without giving the least trouble from air leaks, or, in fact, from any other causes.

A description of the principal details of construction is as follows: The 24-inch suction main is connected directly to the pumps without an air separator or sand receiver. The top of this main is laid from 6 to 8 feet below the surface of the ground, and about 5 feet below the usual level of Charles River during the summer months. The main was laid at this depth for two reasons: First, that more water might be drawn from the ground, and, second, that the main might be in the most favorable position, not to be affected by expansion or contraction due to changes of temperature. The main has a slight pitch from the pump, the farther end being about 6 inches lower. This construction is necessary to allow any air which may be in the pipes to flow toward the station and not pocket at any point on the line.

This suction main is composed of ordinary cast-iron bell and spigot pipes, laid in the usual way with lead joints. Extra pains were taken, however, in calking these joints. During the laying of the main and the connecting of the wells, it was necessary to keep a 6-inch rotary pump running day and night to free the trench from water. The bottom of the trench was a rather fine sand, and the pipe was supported on a blocking reaching to a timber platform placed about 8 inches below the bottom of the pipes to allow room to calk the joints. Short cast-iron Y branches of special design were placed in the main for each well. The 2½-inch outlets of these Y branches were drilled and tapped to a templet at the foundry before being tarred, under the watch of an inspector.

The wells were connected to the Y branches by two lead connections, 2½ inches in diameter and of a weight of 11 pounds per foot. A gate with companion flanget was placed between these lead connections, the flanges forming the union joint between the wells and suction main. The soldering nipples used with the lead connections were made to order of the best steam metal. They were delivered untinned in order that any defect in them could be easily found. Special care was

[1] New England Waterworks Association Jour., vol. 11, No. 3, p. 195, 1897.

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taken to solder these nipples to the lead connections. A wiped joint was not considered to be always air-tight and of this size rather difficult to make, and we finally decided to sweat the nipples in, as this process is sometimes called. The necessary heat was obtained from cast-iron plugs heated in a portable forge which fitted loosely into the nipples. The well pipes were screwed together with special wrought-iron couplings until the ends butted, and special cement was used on the threads. The wells were from 35 to 95 feet deep. Two and one-half inch tees of a special pattern were placed on the wells at a proper grade to allow them to be connected by means of the lead connections to the suction main. The piping of the wells was carried to the height of about 1 foot above the surface of the ground and capped with a special cap. The wells have open ends, no strainers of any kind being used. In the bottom pieces there are five rows of holes with nine holes in a row, spaced 2½ inches apart from centers, and bushed with ⅜-inch brass pipe.

As before stated, we have had no air leaks so far, and as the suction pipe is laid with lead joints, and the connection between this pipe and the wells made with lead pipe, thus making the whole construction flexible, we can see no reason why air leaks should ever occur.

The cost of construction of the work done two years ago, which included laying all of the 20, 16, 10, and 8 inch pipe, and driving 159 wells, is as follows:

Cost of driving and connecting 118 good wells and driving and pulling up 41 poor wells.

Cost of labor, driving wells	$1,561.00
Cost of labor, connecting wells	210.00
Cost of labor, pumping out wells	369.00
Cost of the well pipes, not including bottom pieces	572.06
Cost of the bottom pieces	196.23
Cost of preparing bottom pieces	118.00
Cost of the gate tops for wells	360.37
Cost of the gates	660.80
Cost of 2½-inch tees	94.40
Cost of soldering nipples	250.16
Cost of solder	23.00
Cost of ⅜-inch rope	5.31
Cost of oil	6.25
Cost of red and white lead	23.59
Cost of lead pipe	333.40
Cost of making lead connection in the shop	52.50
Cost of 2½-inch plugs	2.29
Cost of 2½-inch coupling	155.40
Cost of pulling up poor wells	80.00
Cost of Akron pipe for gate boxes	306.92
Cutting threads on pipe	206.72
Teaming	14.00
Miscellaneous	51.26
Total cost of wells	5,652.66
Number of feet of good wells driven	5,977
Number of feet of poor wells driven	1,741
Total	7,718
The average depth of the wells	50 feet.
Average number of feet driven per day with gang of four men	50 feet.
Cost of labor driving wells, per foot	$0.21
Average cost of each good well, including driving and connecting and expense of driving and pulling the poor wells	$47.90

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Cost of laying the suction main.

Cost of labor	$10,428.32
Cost of lumber	1,118.55
Cost of pipes	6,248.07
Cost of gates	341.16
Cost of lead	515.09
Cost of pumping, the engineer	458.56
Cost of pumping, coal	174.71
Cost of unloading pipes	39.00
Cost of inspecting pipes	183.00
Cost of rubber boots	210.00
Cost of shovels	52.00
Cost of carting men to and from work	947.30
Cost of hauling the pipe from cars	300.00
Cost of expressage	79.30
Cost of oil for engine	4.80
Cost of jute packing	12.74
Miscellaneous	155.43
Total cost of laying pipe	21,268.03
The amounts laid are as follows:	
20-inch pipe	2,023 feet.
16-inch pipe	551 feet.
10-inch pipe	1,420 feet.
8-inch pipe	155 feet.
	4,149 feet.
The total cost of laying pipe	$21,268.03
The total cost of driving and connecting wells	5,652.66
Total cost of system	26,920.69
The total cost of laying the pipe, driving and connecting wells, per foot of suction main	6.45

Plant at Brooklyn, N. Y.—The borough of Brooklyn, N. Y., obtains a large part of its water supply from driven wells arranged in gangs at several places on Long Island. The first wells constructed were of the closed-end type, but later ones are of the open-end type. The wells are arranged in two rows, one on each side of the suction main, the wells in some gangs being in files and in others staggered. A description of one of the new plants is as follows:

The main suctions are about 2,340 feet long with a fall of 12 inches from center to each end. The 62 wells are staggered along the main suction pipe, 12 feet from it and 75 feet apart on each side. Their average depth is 45 feet, a stratum of fine sharp sand being met with at that depth. The outside casing is 4½ inches, with a 6-foot strainer, 2-foot sand pocket,[1] and 6-inch point. Suctions are 3 inches in diameter and 28 feet long. Lateral branches are 3½ inches, and each is provided with a gate. It is expected to get 6,000,000 gallons from this station. The contract price for the last 25,000,000 was $167,250 for sinking and connecting wells, the yield to be determined by a test lasting one year and taken as the lowest average for five consecutive days.[2]

[1] A sand pocket is a large drum or box inserted in the suction pipe to catch sand that is drawn up with the water. It is provided with handholes to facilitate cleaning.

[2] Turneaure, F. E., and Russell, H. L., Public water supplies, p. 308, 1909.

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Plant at Plainfield, N. J.—The following is a description[1] of the driven-well system at Plainfield, N. J.:

The region itself is a comparatively level valley, some 7 miles long and from three-fourths to 2 miles wide, is fairly well wooded, and slopes gently to the westward. It is divided by a small stream running to the southwest, having several short tributaries; together they furnish excellent surface drainage for the city.

The soil consists mostly of sand, clay, and gravel strata, rock not being encountered, except at considerable depths.

It has always been an easy matter to procure water in abundance for domestic use by driving pipe wells from 20 to 80 feet deep at each residence, and attaching pumps directly thereto; and for fire supplies, sinking large brick curbs some 15 or 20 feet into the gravel gave an abundant flow. But obviously, with the increasing population and no sewerage system, individual wells became a source of danger to health, yet for nearly 20 years no definite result was accomplished, more than the mere organization of a private water company.

In 1890 active measures were taken and tests and examinations made, which finally resulted in the sinking of pipe wells on a plot of ground 1½ miles east of the center of the city in a soil where the upper clay stratum was some 30 feet or more in thickness, underlain by a very coarse water-bearing gravel. This spot was selected for its freedom from probable contamination on ground slightly higher than the city, which at the same time was convenient.

Several test wells were sunk at various points previous to the observations of the writer, and pumping tests made with a low-lift pump of a number of the main wells then driven, under the care of Mr. Rudolph Hering, M. Am. Soc. C. E. The quantity of water obtained from 10 wells for periods of eight hours' daily consecutive pumping, during two weeks of observation, was at the rate of from 2,000,000 to 2,125,000 gallons in 24 hours.

An inspection of Plate III [IV in the present report] will show the final arrangement of the wells, test wells, pumping plant in general, and details of the well tubes. The construction of the cast heads is such as to transform each water tube into practically an open well, giving atmospheric pressure free play rather than forcing its action through the earth, as in systems where but a single tube is used. The most distant well is 500 feet from the pumps and shows in an interesting manner by the vacuum at the well head and increased vacuum at the pump the effect of long suction and friction in the main.

The 2-inch pipe test wells * * *, were observed daily by the writer, while resident engineer, during several months. They each had a simple balanced float gage and scale, which indicated the rise and fall of water level. They were all very sensitive to draft on the main wells when pumping was going on, though the nearest was 200 feet from the line of wells.

Comparison of these observations under the different conditions and seasons showed, among other things, that in about 1,900 feet the underground water level fell to the westward about 3 feet, or at about the same rate as the average surface of the ground. This evidenced conclusively that the flow of water was toward the city with a head sufficient to prevent any back flow of contaminated waters from the city.

In summary, the plant consists of 20 wells 6 inches in diameter from 35 to 50 feet in depth each, ranged in a double row on a strip of land 25 feet wide and 1,000 feet long, having in each a 4½-inch open-end suction tube, connected with a wrought-iron main varying from 8 to 12 inches in diameter. This main is in two sections, each 500 feet, connecting 10 wells.

Two compound surface-condensing duplex plunger pumps, Worthington make, one of 3,000,000 and one of 2,000,000 gallons daily capacity, and a boiler plant of

[1] Tribus, L. L., Am. Soc. Civil Eng. Trans., vol. 31, No. 700, pp. 371 et seq., 1894.

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sufficient power, with various essential small machines, are housed in a rough-stone building, slate roofed.

The water, drawn as before stated, direct from the wells, is pumped into a wrought-iron standpipe (situated near at hand) 25 feet in diameter and 140 feet high, through a 20-inch interior tube rising 5 feet above the top. Two lower openings on this rising main, with valves operated from the outside spiral staircase, afford opportunity for filling the standpipe at lesser head if required.

The object of this interior tube, which was almost unique when erected, is threefold:

First, by its fountain action, enforcing complete aeration.

Second, complete circulation.

Third, to afford instant fire pressure, no matter what the elevation of water in the main tower. This is accomplished by opening a by-pass, not otherwise used, connecting the rising main and the distribution line, the city's supply being drawn regularly from the bottom of the standpipe with pressure due to level of water in main tower.

From the standpipe the Plainfield pipe system extends to the west, comprising some 30 miles of mains from 6 to 16 inches in diameter, having fire hydrants spaced about 11 and valves 6 per mile. * * *

After the tests made by Mr. Hering and the partial completion of the works, various other tests were made with the permanent pumping plant. It was found that the wells on the westerly line yielded more abundantly than the easterly ones, under equally good conditions, and gave a lower vacuum for the same quantity pumped. * * *

The tests were made with the large pumps, under both free discharge and full working head, singly and together, and drawing from the wells in groups of 5, 10, 15, and 20, using each combination of 5; also, by cutting off one by one until the smallest number that could be used was reached, then adding one by one in reverse order until the full series were again in use. Five wells were found to be the smallest number possible to use and run the pumps smoothly. Wells Nos. 6 to 10 gave the best results, while Nos. 16 to 20 furnished but little water. The best results were obtained for a full flow by using Nos. 1 to 15 inclusive. * * *

During the long-continued dry weather of 1891 the water level became so low that difficulty arose with the extreme suction lift obtained, from 20 to 28 feet, according to rate of pumping, a fall of some 6 or 7 feet since the earlier observations, so that in the summer of 1892 it was deemed best to lower the pumps, which was done to the depth of 8 feet 1 inch below the former positions.

For the sake of a constant observation and record, a 3-inch open tube was driven from the engine room into the water-bearing gravel, and a permanent float gage suspended in it, indicating by a balanced point on a scale of feet placed conveniently in the room. Although some 80 feet from the nearest main well, therefore not showing the lowest level of the water at the wells when pumping, it does show the relative water level under the same conditions and the daily and monthly range. When pumping, the average lowering of the gage is about 8 inches, with an almost immediate return after stopping the pump.

Rainfalls need to be exceptionally heavy to make any marked showing in the water level, and not much then inside of 24 hours. This seems to indicate that the water supply comes from a distance, but there is an insufficiency of data for determining this interesting point.

In these two years or more of operation, the wells have furnished daily, without difficulty or signs of falling away, the full demand of from 200,000 gallons at the start to 1,700,000 gallons at the present time, apparently derived, as the early tests indicated, from the western 15 of the 20 wells driven. The water itself has been of uniformly excellent quality, both for domestic and manufacturing purposes; so far, therefore, a decided success as an underground water supply.

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GROUND WATERS FOR PRIVATE USE.

Most of the private wells in Connecticut are used for domestic supplies, although a few are used by manufacturing plants. The problems involved in obtaining a supply of good water from private wells have seldom been seriously considered. Many of the wells were dug before present-day ideas of sanitation became prevalent; they were constructed in the best manner possible under the circumstances, and for a long time they have been regarded as admirable relics of earlier days; and there is a disposition to copy them even at the expense of both sanitary and economic considerations.

Sanitary precautions are necessary not only in the case of dug wells but also in the case of springs and drilled wells. Springs are especially susceptible to pollution because the water is obtained at the surface and almost always on a slope where surface drainage can readily enter the pool. Springs should be equipped with a concrete reservoir and kept covered, and the water should be drawn from a delivery pipe. Such an equipment is not necessarily elaborate or expensive. It is important only to provide for the exclusion of surface drainage and the prevention of contamination either by persons or animals by preventing access to the stored water. Drilled wells properly constructed by reliable drillers exclude surface waters. If the well casings are properly set and the pump fittings are tight, such wells are in little danger from pollution.

The average per capita consumption of water from private wells is much less than the consumption from public supplies, largely owing to the general lack of convenience in well equipment; consequently the amount of water required will depend on the equipment to be installed. For example, about ten times as much water will be required if a pneumatic or a tower system is to be installed for the purpose of furnishing running water in the house and barns as if the equipment were to consist merely of a hoisting bucket or a small hand pump. The type of well is also a factor. An ordinary dug well yielding continuously 2 gallons a minute might, because of its storage capacity, meet a temporary draught of 50 or 100 gallons a minute; whereas a driven well, having no stored supply, could not meet a draught in excess of its maximum yield. Therefore, the estimate of the quantity required should be based not only on the total amount of water used in a day but also on the greatest rate at which it is to be pumped from the well.

The water delivered by springs is, in general, of the same quality as the water to be obtained from shallow wells in their vicinity. Therefore the choice between opening up a spring and sinking a well depends on the relative cost and the resulting convenience. Springs so situated that water may be delivered to buildings by gravity afford very desirable supplies, but springs situated at low

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elevations and therefore requiring pumping afford no more economical supplies than dug wells.[1]

The water obtained from dug wells is slightly harder than surface water, but in Connecticut the difference is ordinarily not appreciable, well waters, so far as their mineral quality is concerned, being suitable for ordinary domestic use.

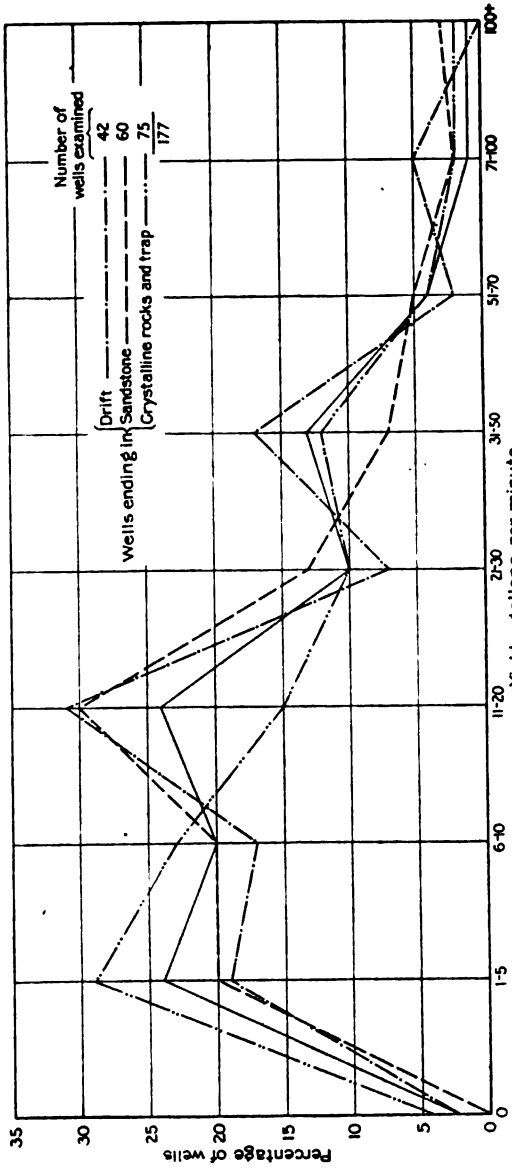

FIGURE 8.—Curves showing yield of drilled wells.

Dug wells generally afford satisfactory domestic supplies, but they should not be expected to do so without some attention. Wells, especially open wells, that have not been cleaned for 25 years and yet remain serviceable are not always things to be proud of, a fact that is generally discovered when the wells are cleaned.

Where the unconsolidated material consists of sand or gravel, driven wells are likely to be more convenient than wells of other types. Driven wells are especially adapted to use in gardens, pastures, and barn yards, where water is required for stock and plants and where dug wells would be objectionable.

The water from driven wells is of the same mineral quality as that from dug wells in the same vicinity since it comes from the same source, and it is to some extent susceptible to pollution.

[1] Fuller, M. L., Underground waters for farm use: U. S. Geol. Survey Water-Supply Paper 255, 1910.

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Therefore the surroundings of driven wells should be kept scrupulously clean.

Drilled wells generally yield at least 2 or 3 gallons a minute, a quantity adequate for most households. (See fig. 8.) The water is generally suitable for domestic uses, although in Connecticut it may be harder than the water of shallow wells.

METHODS OF DEVELOPING GROUND-WATER SUPPLIES.

DRILLED WELLS.

CONSTRUCTION.[1]

Two general methods of well drilling are employed in obtaining water supplies, namely, the percussion method and the abrasion method. In Connecticut the percussion method is most commonly used. It consists of lifting and dropping, by means of suitable apparatus, a heavy string of drill tools which punches or cuts a hole through the unconsolidated materials and breaks the solid rock into fragments small enough to be removed from the hole. When drilling is done in unconsolidated material iron pipe or well casing as large in diameter as the hole will admit—usually either 6 or 8 inches—is generally driven down as rapidly as the drill descends, each added length of casing being securely screwed to the preceding one to make a tight joint. If the well penetrates bedrock, the casing is driven a few feet into the rock to prevent infiltration of surface water. If the well ends in loose materials the casing extends to the bottom of the hole and may be perforated or slit at the lower end to admit water more rapidly. The casing is allowed to extend several inches above the surface of the ground to prevent inflow of surface water, and a flange is fitted to the top, to which a pump is attached.

In drilling by the abrasion method hollow drill tools armed with some harder materials, such as diamonds or chilled shot, are rotated on the rock in such a way that a cylindrical core is cut out and brought to the surface in short pieces. The wells sunk by this method are finished in the same way as those made by percussion drilling.

Drillers differ in opinion as to the relative efficiency of these two methods, the points of contention being that the abrasion method is more expensive and that the rotation of the drill tools tends to seal up the smaller veins, thereby affording a comparatively lower yield than is obtained by percussion drilling. Data bearing conclusively on these questions are lacking, but the fact remains that both methods are used, the percussion method to a much larger extent, and that good results are obtained by each.

[1] Bowman, Isaiah, Well-drilling methods: U. S. Geol. Survey Water-Supply Paper 257, 1911.

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COST.

Owing to the competition among well drillers there is no uniform scale of prices for drilling wells. The minimum prices charged range from about $1 to $4 per foot, including the casing. Usually the minimum price is charged for the first 100 feet and an additional charge of about $1 per foot is made for each succeeding 100 feet or fraction thereof. Other factors which affect the prices are the character of the bedrocks and depth of the unconsolidated materials; the accessibility of fuel and water for the engines and the distance from the well to suitable lodging places for the drillers.

No reliable driller will agree to obtain a water supply within a given depth in the bedrocks of the Waterbury area. A driller may offer to obtain a certain amount of water for a stated sum of money, but as he can not predict the depth or the location of a successful rock well such an arrangement amounts to little more than a game of chance, in which the advantage is necessarily largely on the side of the driller.

QUALITY OF WATER.

Drilled wells are usually protected against contamination by their manner of construction and this is one of their chief advantages. The principal disadvantages of drilled rock wells lies in the fact that neither the quantity nor the mineral quality of the water can be definitely ascertained before drilling and consequently an expensive well may be drilled without obtaining a suitable supply.

The water from drilled wells that end in the drift at depths of 75 or 100 feet is just as likely to be free from pollution as that from wells that end in rock, and it is less likely to contain undesirable amounts of mineral matter. Moreover, drilled wells that end in the rock are not invariably free from pollution, especially where the rock outcrops or lies a short distance below the surface, owing to the possibility of the passage of infected matter through open rock fissures to the well. Many rock wells situated near the coast are contaminated by salt because some of the fissures intersected by the well come to the surface below tidewater. The contamination in such wells is easily detected, but it is not so easily detected if fissures contributing to the water supply come to the surface in barnyards or in the beds of polluted rivers. It is not necessarily a fortunate thing if a well strikes a vein that yields water giving an "odor of sulphur" because odors not easily distinguishable from "sulphur" may be due to pollution. The origin of any odors, colors, or tastes should be determined before a water is used. Even deep drilled wells may be contaminated in a thickly populated community unless the protective cover of clay is thick and the casing is water-tight and fits tightly into the drill hole.

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IMPROVEMENTS.

Drilled wells which end in the drift do not differ essentially from driven wells, and they should be finished in the same manner. The casing should be perforated or slit at the principal water-bearing horizons and for some distance above the lower end. This will generally increase the yield materially.

Some wells that produce water of an undesirable mineral character may be improved by casing off the mineral water and drawing from a different horizon. This method is not likely to be generally successful in Connecticut, however, because the quality of the groundwater does not differ very much from one local horizon to another.

If the yield of a well is reduced by pumping from other wells in the vicinity the pump cylinder should be lowered, and if this does not recover the yield, deepening the well may do so; but there is likely to be more or less permanent interference when a number of wells are drilled close together. A method of increasing yields of drilled wells which has not been used sufficiently to warrant its recommendation for general use consists of exploding a charge of nitroglycerine or dynamite at the bottom of the well, the object being to develop radiating fissures that may tap otherwise unavailable water veins. This method is used extensively in improving oil wells, and there appears to be no reason why, under favorable conditions, it should not be equally beneficial in water wells. In many cases it would be advisable to try this remedy before abandoning dry holes ending in rock. It is not recommended for wells ending in drift.

DRIVEN WELLS.

Two general types of wells are classed as driven wells, namely, the closed-end well and the open-end well. A closed-end well is constructed by driving into the ground with a sledge or drop hammer a "drive point" and strainer screwed to a piece of pipe. Other lengths of pipe are added and the driving is continued until the strainer penetrates the groundwater horizon (fig. 9). The diameter of the pipe and strainer may be 1 inch to 4 inches and the length of the strainer is usually between 1½ and 4 feet.

The open-end well is constructed by driving a casting into the ground and at the same time removing the material from the interior by means of a sand bucket or sand pump or a jet of water. If the formation is rather hard, it may be necessary to remove the material in advance of the casing by means of a heavy sand pump or combination jet and drill, or ordinary drilling may have to be done. A strainer may be attached previous to driving, or it may be adjusted after the casing is down by lowering it on the inside. Where the water-bearing deposits include coarse material and large quantities of

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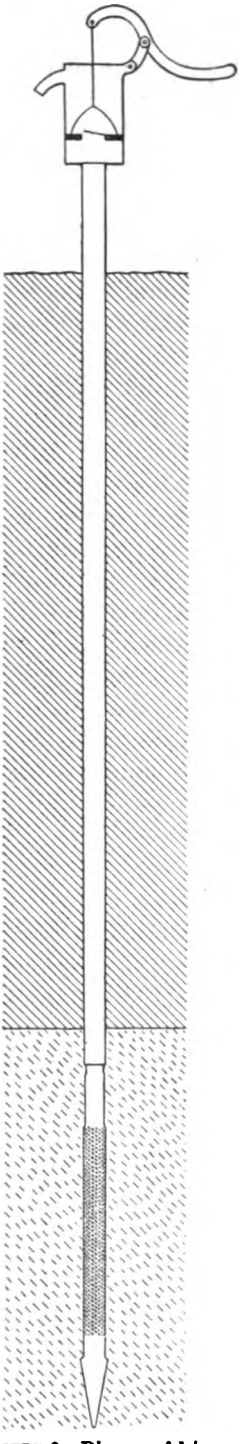

FIGURE 9.—Diagram of driven well.

water are desired, as for muni
dustrial supplies, the most satis
sults will be obtained by not us
the ordinary strainers, but by
the casings where water is to b
with numerous circular holes at
fourth inch in diameter or slits a
fourth inch wide. These perfor
be cut or drilled before the cas
serted, or they can be made by
tools after the casing is in place.[1]

After the casing is in place and th
tions have been made the well s
thoroughly cleaned out, in order t
the fine sediments and give the w
access to the well. This can best b
first using a sand bucket or sand p
then applying an air lift. If an air
available, rapid pumping with a ce
or other pump can be substituted.
wells can often be developed by r
large quantities of sand and silt a
leaving a thick layer of clean gravel
the intake of the well. Wells of th
are better adapted for harder grou
larger diameters than the closed-en
The use of drive points is restricted t
in which water can be obtained in rat
gravel or sand at moderate depths, but
end wells may be used in almost an
consolidated deposits and they may b
to depths of several hundred feet.
probable that in Connecticut either
points or the usual drilled wells ending i
drift and having the casings perforated
be found satisfactory.

Driven wells are used both in dom
and in municipal supplies. For dom
purposes it is seldom that more than
well is required to furnish the desired amo
of water, but for public supplies for la
towns these wells are commonly driven
gangs, arranged in one or two rows alo
a suction main to which each well is co

[1] Bowman, Isaiah, Well-drilling methods: U. S. Geol. Surv
Water-Supply Paper 257, pp. 67–69, 1911.

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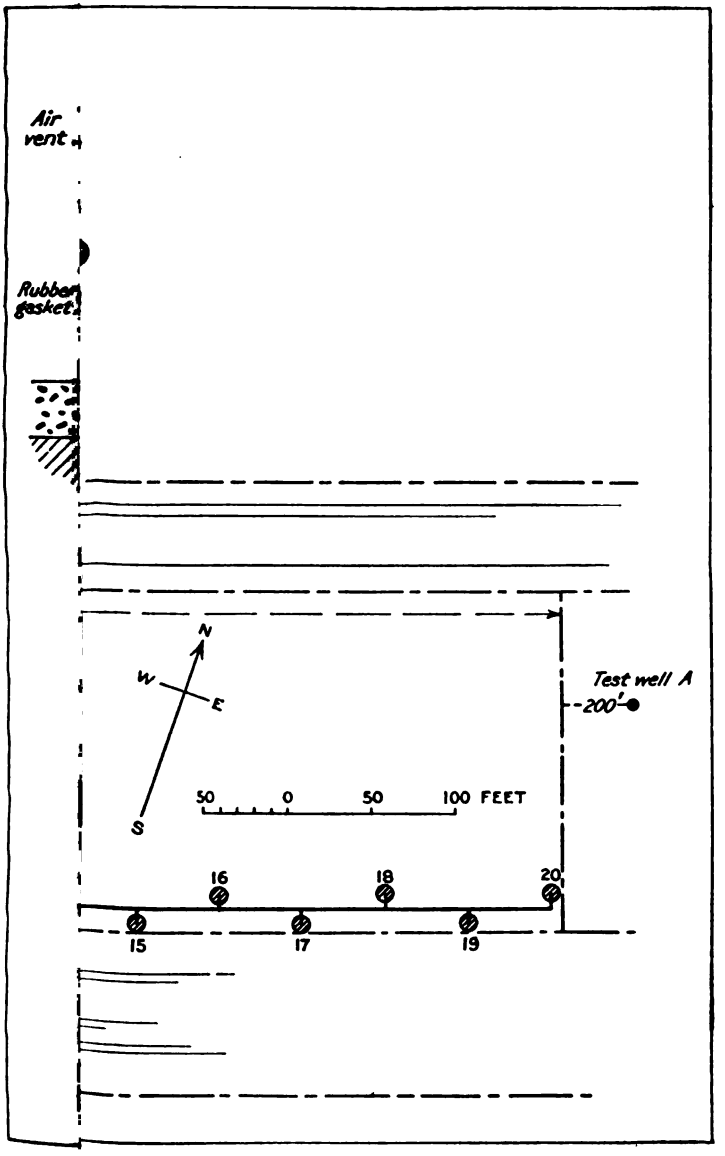

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nected by a lateral branch (Pl. IV). The most economical system is one in which the suction main can be laid on the surface of the ground, but in some systems, either for the purpose of obtaining the maximum yield or because the water stands below the suction limit from the surface, it is necessary or desirable to lay the suction main in a trench.

It is not possible to give figures in regard to the requisite number of wells and their size and spacing that would be everywhere applicable, owing to the diverse conditions under which such plants are used; but in general it is advisable to place the line of wells at right angles to the direction of underflow, and the distance between the wells should be between 15 and 100 feet, depending on the size of the wells. The number and size of wells to be used will be determined by the amount of water required, the size and character of the water-bearing formation, and by the results of pumping tests to determine the permeability of the formation.

One of the principal difficulties encountered in the operation of driven wells is clogging. Infiltration of fine sand or incrusting of the strainer may reduce the yield of a well materially, and it is necessary, therefore, to keep the tube clean. It is usually advisable to subject a newly driven well to heavy pumping for the purpose of drawing out the fine material adjacent to the strainer. Coarse material will be left in its place, forming a natural screen, which will minimize the tendency to clogging, and the yield of the well will be increased by the consequent increase in the porosity of the material surrounding the screen.[1] When clogging is due to sand only it is usually possible to remove the obstruction by forcing water into the wells under high pressure or by means of a steam jet, but when the sand is cemented it is necessary to withdraw the strainers to be cleaned or replaced by new ones.

The liability to pollution of supplies from driven wells depends on the depth from which the wells draw, the effectiveness of overlying clay beds in shutting out pollution, the amount of water that is drawn, and other conditions. Though the danger of pollution is less than in open dug wells care should nevertheless be exercised in the selection of sites and in protecting the surroundings against contamination. Where large supplies are developed, such as are required for large municipalities, there is danger of drawing polluted water from near-by streams though smaller supplies drawn from the same wells might not be in danger of pollution.

INFILTRATION GALLERIES.

Infiltration galleries are trenches or tunnels, with sides and roofs constructed usually of masonry or concrete and the floors made to admit water. Galleries may be built in the banks or beds of streams

[1] Meinzer, O. E., Geology and underground waters of southern Minnesota: U. S. Geol. Survey Water-Supply Paper 256, p. 86, 1911.

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for the purpose of intercepting the underground drainage as it approaches the streams. The deposits in filled valleys are saturated below the level of permanent streams, and galleries located in such deposits offer practicable means of obtaining water supplies. The bottom of a gallery may profitably be made lower than the bed of the stream to insure the maximum infiltration. Water from the stream itself does not enter the gallery unless the draught on the gallery exceeds the infiltration from the landward side. A gallery is a modified form of dug well, from which it differs essentially only in capacity and the same sanitary rules apply to both.

DUG WELLS.

The most common type of well is a dug hole, 2½ to 4 feet in diameter and deep enough to procure a suitable supply of water. The hole is then walled up from the bottom to the surface of the ground with loose irregular stones and bowlders picked up in the vicinity of the well. Brick laid in mortar and glazed tile have been used to a small extent for walls, but these materials, although much more desirable for the purpose, are more expensive than the stone commonly used. The top of the well is commonly finished by fitting a square curbing of boards over the hole and adding a wheel or windlass for hoisting a bucket. Better equipments, ranging from screened well sheds to concrete seals with good pumps, are found in many wells. Wells of this type generally end in the drift, but in areas where the drift is thin they may end at the rock surface or penetrate the rock a few feet, in which case the rock is removed by blasting. The principal advantages of the wells of this type are the ease with which they may be cleaned and refitted with pumps, and the large storage capacity; the chief disadvantages are their liability to pollution and their response to changes in the weather.

The following extract [1] regarding the essentials of a good well is an excellent summary of the proper sanitary construction of dug wells:

> The location of the well is of the greatest importance. It should be as far as possible from the house, barn, and privy. If possible, the surface of the ground about the well should be a little higher than the surrounding soil so that any surface washings may be carried away from the top of the well. The ground about the top should be well sodded in grass. This not only adds to the attractiveness of the well but it takes care of a great deal of water that would otherwise have to stand in pools about the well. If the stock have to be watered from the well, there should be a pipe leading to a stock trough not less than 20 feet away, so that the stock need not come up to the well itself.
>
> A well, to be safe, should be not less than 20 feet deep. That is to say, 20 feet from the surface of the ground to the top of the water. It should go well through the surface soil, preferably through a layer of clay. The lining should be of brick or stone laid in cement. Any lining that allows water to seep through it above the

[1] Virginia Health Bulletin, vol. 1, p. 113, September, 1908.

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surface of the water may lead to pollution. The space between the casing and the surrounding soil should be filled with sand or earth.

The top of the well should be raised from the ground about a foot and set in cement or masonry coping that goes at least 3 feet below the surface of the ground. Over the top should be laid a solid, double tongue-and-groove flooring that is absolutely waterproof. This is essential. Most wells are polluted by material that falls in or is washed in from the top, and not by seepage through the soil.

On the well top there should be a good pump, carefully set so as to exclude leakage from around its base. If the pump can not be used there should be an automatic tipping bucket. The well bucket should not be handled with the hands. Many wells have been infected by handling the bucket with soiled hands and then letting it back into the well, the filth being then washed off into the water.

Below the spout there should be a trough with a pipe leading some distance away so that the waste water may be carried away from the well.

A well constructed in the manner described above will almost always furnish water that is perfectly safe, and the saving of sickness and trouble will many times overpay for the expense and care involved.

For convenience in discussion, dug wells may be divided, according to their relation to bedrock, into groups to include, first, wells that penetrate bedrock; second, wells that just reach rock; and third, those that end in drift.

Wells that penetrate bedrock are sunk in localities in which the drift is thin. The thickness of the water bed in the vicinity of such wells may be less than the normal fluctuation of the water table, and consequently in times of drought there may be no available water in the drift. But the rock basins generally act as reservoirs for the storage of water which has seeped in from the drift, and these wells therefore usually carry small supplies through dry seasons. In cleaning rock wells, and sometimes in digging them actual veins of water are encountered, and this has led to the belief that the well supply is derived from some deep sources in the bedrocks. While such a condition is possible, most of these "veins" are shallow, water-filled cracks, developed naturally in the rock or produced by blasting. These cracks, radiating from the well, tap all along their courses the saturated zone of the overlying drift, and thus make it possible for the well to drain a much larger area than it otherwise could.

Wells that extend to the surface of the bedrock are usually found in areas of thicker drift than are those which penetrate the rock. Like the rock wells they pass entirely through the saturated part of the drift but they do not contain a stored supply and therefore fail if the water table sinks to the rock surface. Consequently in localities where both types are found the supplies of the rock wells last longer in times of drought, although the others, drawing from a greater average thickness of saturated deposits, have a greater average yield.

Most of the wells that do not reach rock are found in areas of deep drift. These wells are sunk below the water level to a depth which at the time of digging is considered sufficient to supply the required

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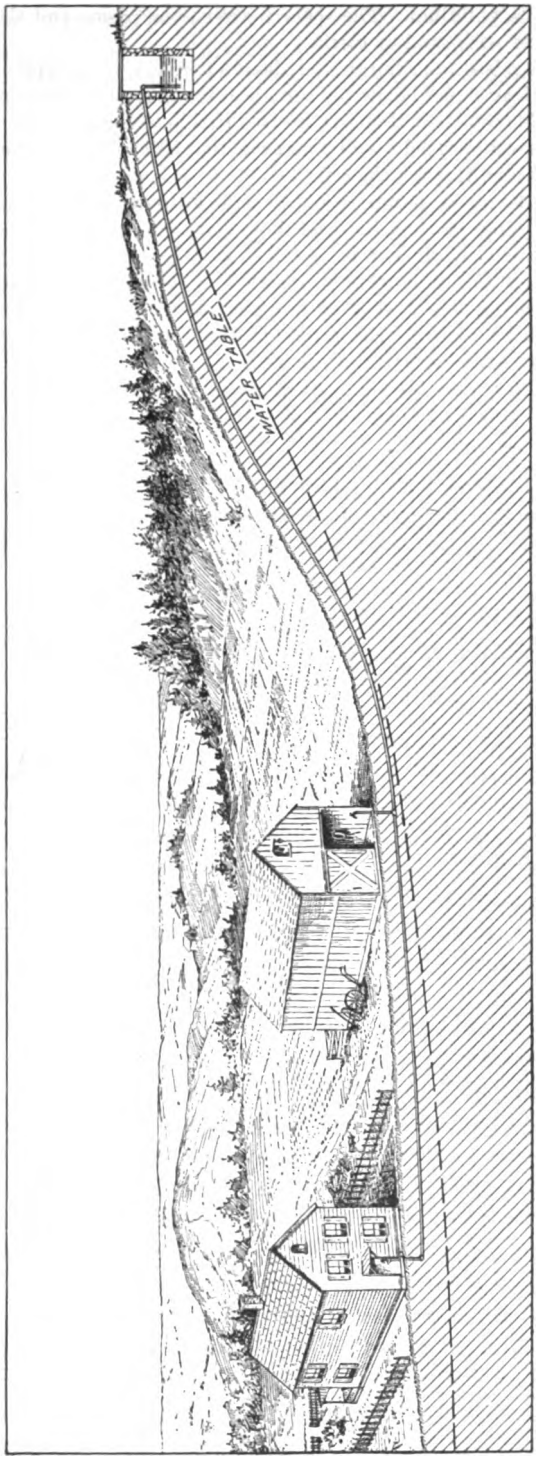

FIGURE 10.—Sketch showing siphon well and domestic waterworks.

amount of water. Most of the wells which fail are of this kind, the failure being usually due to some one of of the following causes:

(*a*) The well may be too shallow. To be reliable it should be sunk at least several feet below the lowest water level. This can be most easily accomplished during dry seasons.

(*b*) The well, originally deep enough, may become "filled in" with sand and mud carried by inflowing water. In this manner the bottom of the well may be raised in wet seasons, when the water table stands high, to a level below which the water table sinks in dry seasons.

(*c*) There may be a permanent lowering of the water table so that the bottom of the well lies within the zone of fluctuation. This may result from tiling, from a heavy draught on wells, or from lowering surface drainage either by removing dams or by deepening the channels of neighboring streams.

Wells that end in the sand or loose till should be cleaned about once a year. Wells that end in the rock may require attention less often. In

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any case cleaning should be the first remedy employed to restore the yield of a well. If this is not effective then the well should be deepened, and if this is done when the water is lowest it will be easy to judge the necessary depth.

Wells may be deepened without disturbing the old wall by sinking 18-inch or 24-inch tiling from the original bottom to the required depth. A method sometimes employed where the well ends in sand consists in driving a "point" (p. 34) into the bottom of the well to the necessary depth. If the strainer is more than 25 feet below the surface of the ground—that is, below the suction limit—the pump cylinder may be attached at some point between the surface of the ground and the bottom of the dug well. In some cases, especially those in which the well ends in rock, the most feasible way to obtain a suitable supply is by drilling from the bottom of the old well. This amounts practically to constructing a new well except that the cost of drilling to the depth of the old well is saved.

An adaptation of the dug well which is popular in some parts of Connecticut is illustrated in figure 10. This consists in placing a well on a hillside above the house and barns so that water may be delivered to the buildings by gravity and under pressure. This is an excellent device wherever it can be used.

DESCRIPTIONS OF TOWNS.

ANSONIA.

POPULATION AND INDUSTRIES.

Ansonia is in the western part of New Haven County near the mouth of Naugatuck River. It is reached by the Berkshire and Naugatuck divisions of the New York, New Haven & Hartford Railroad and by the Derby division of the Connecticut Co.'s Electric Railway. Ansonia was separated from Derby and incorporated in April, 1889. Its area is 6 square miles. The town and city are consolidated.

The population in 1910 was 15,152. The census reports for 1900 and 1890 give 12,681 and 10,342, respectively. The principal industries are the manufacture of brass and copper articles, iron casting, and general foundry work.

TOPOGRAPHY.

The east boundary lies along the divide between Wepawaug River and Naugatuck River, and the town extends westward to the top of the west valley wall. The highest elevation—450 feet above sea level—is about the middle of the east boundary, and the lowest—about 18 feet above sea level—is at the place where Naugatuck River crosses the south boundary of the town. The valley floor in Ansonia has an average width of about 1 mile.

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Naugatuck River receives all the drainage except that from a very small area in the southern part of the town, which enters the Derby reservoirs. About one-fourth of the town is wooded, the timbered areas including most of the northeast quarter and some of the slopes in the southeast and northwest quarters.

WATER-BEARING FORMATIONS.

Bedrocks.—The Prospect granite gneiss and the Orange phyllite (p. 9) compose the rock floor of Ansonia. These rocks are dense, and it is only through their ramifying system of joint cracks that they are capable of furnishing moderate supplies of water (p. 17). The bedrocks are exposed in the hills and on some of the slopes, as indicated in Plate III, but exposures are not so numerous here as in Seymour.

Till.—Unstratified mixtures of clay, sand, gravel, and bowlders deposited by the last retreating glacier constitute the rock cover on the hills. It ranges in thickness from a few inches to 30 or 40 feet and yields moderate domestic water supplies where the thickness exceeds 10 or 15 feet (p. 11).

Stratified drift.—Stratified deposits, consisting of poorly sorted sand and gravel, occur along the river, and a few small deposits are found in the valleys in the eastern part of the town. The stratified deposits along Naugatuck River are capable of yielding supplies to shallow wells, but the deposits in the eastern part of the town, on account of their topographic position and their small extent, are not important as water-bearing formations (p. 13).

SURFACE-WATER SUPPLIES.

Surface waters are used to a moderate extent both for power and for domestic consumption. The brook that rises in the southeast corner of Seymour and joins Naugatuck River at Ansonia is the principal source of the Ansonia supply. The Ansonia Water Co. maintains an ice pond on this brook near Ansonia, and not far below it is a dam that furnishes power for the Cook machine shops. A dam in Naugatuck River just north of the Seymour line diverts water into a power canal which, together with a dam at Ansonia, furnishes power for factories in the city. A site for a small storage reservoir near the headwaters of Twomile Brook is said to be regarded by the Ansonia Water Co. as a possible additional source of supply for the city.

According to tests of monthly samples from Naugatuck River at Ansonia made by the Connecticut State Board of Health from 1894 to 1897 the water of that stream contains an average of 54 parts per million of total solids, 16 parts of which is volatile matter and 3.8 parts is chlorine, and has a total hardness of 14 parts and a color of 39 parts.[1]

[1] Compiled from data in annual reports of the State Board of Health of Connecticut for 1894–1897.

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GROUND-WATER SUPPLIES.

The 11 dug wells which were examined range in depth from 11 to 35 feet and average 19 feet. The depth to water ranges from 9 to 29 feet and averages 16 feet. Most of the wells are of the ordinary open type, walled with cobblestones, and equipped with a rope and bucket lift. The supplies obtained from these wells are generally adequate for ordinary domestic needs. Only one of the walls is said to fail, but it is probable that failures would be more common if the city water were not so generally available.

Six drilled wells were examined, three of which were said to be 70 feet deep. The meager data in regard to these wells are given in the table on page 43.

Owing to the small area of Ansonia and the possible extension of the public water systems, it is not likely that private ground-water supplies for domestic use will be in great demand. It is probable that if new developments are undertaken because of its low cost the dug well will continue to predominate. In all parts of the town outside that represented by the dotted area in Plate III till or rock, or both, will be encountered in sinking a well. Water will be obtained at a depth of about 5 to 20 feet, except on some of the steepest drift-covered slopes, where the depth may in some places exceed 20 feet. The rock surface is very uneven and may be encountered at any depth below the ground, but where the depth is less than 10 feet it would usually be more economical to drill a well than to dig one. The amount of water available by means of dug wells will generally be adequate for ordinary domestic needs. In the area of stratified drift (Pl. III) shallow dug wells are very likely to be contaminated, and if private supplies are desired they should be obtained by means of drilled or deep-driven wells.

On account of the thinness of the drift most drilled wells draw their supplies from the bedrocks. Supplies from this source vary largely in quantity, and the success of any particular well can not be predicted. However, most of the drilled wells furnish ample supplies for domestic needs, so that it is reasonably safe to invest in drilling if that kind of a supply is desired.

Driven or drilled wells ending below the river level in stratified deposits would doubtless yield large supplies, but if the draft were heavy and continuous it is probable that sooner or later contaminated water from Naugatuck River would be drawn from the wells.

PUBLIC WATER SUPPLIES.

Ansonia is supplied with water by two private companies. The Fountain Water Co. supplies that part of the city lying west of Naugatuck River and the Ansonia Water Co. supplies all of the

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city east of the river. The works of the Fountain Water Co. include a reservoir in Derby, from which water is delivered by gravity.

The Ansonia Water Co., of which Theodore L. Bristol is president and F. J. Davis superintending engineer, has one high-pressure reservoir, one low-pressure reservoir, and one distributing reservoir. The high-pressure reservoir covers 43 acres, is controlled by a masonry dam 20 feet high at an elevation of 326 feet above sea level, has a capacity of 200,000,000 gallons, and affords a pressure of 90 pounds in the city. The low-pressure reservoir is controlled by a masonry dam 15 feet high at an elevation of 138 feet above sea level and furnishes 20 pounds' pressure in the city. Its capacity is 33,000,000 gallons. The distributing reservoir is 266 feet above sea level, is controlled by an earth dam, with masonry spillway 35 feet high, giving a pressure of about 60 pounds. Its capacity is 12,000,000 gallons. There are 19 miles of mains, 102 hydrants, and about 900 service connections.

The maximum daily consumption is 5,000,000 gallons and the average daily consumption 1,250,000 gallons. About 10,500 people are supplied, and when, at the end of the season, no shortage is anticipated, water is supplied for industrial uses. The cost of construction was about $290,000, the cost of operation about $450 ($456.04 in 1912), and of maintenance $2,600 ($2,600.87 in 1912). The income is about $36,500. Charges are based on both meter and flat rates. The supply is adequate for the present, and plans are in hand for an extension of the system when that becomes necessary.

RECORDS OF WELLS.

Information concerning dug and drilled wells in Ansonia is presented in the following tables:

Dug wells in Ansonia, Conn.

Map No.[a]	Topographic position.	Elevation above sea level.	Depth.	Depth to water.	Elevation of water table above sea level.	Cover.	Remarks.
		Feet.	*Feet.*	*Feet.*	*Feet.*		
1	Hill	260	35	20	240	Open	12 feet to rock.
2	Hill	225	12.5	9.2	216	Mesh	
3	Slope	155	20.6	18.6	134	Lattice	
4	Flat	145	12.9		132	Lattice	Use city water largely.
5	Slope	345	[b] 18.0		327	Closed	
6	Slope	315	12.0	9.2	303	Open	
7	Slope	125	14.0	11.2	111	Open	Not used.
9	Slope	390	16.0	15.5	374	Open	
12	Slope	340	11.2	10.0	330	Open	Use not over 10 gallons a day.
15	Hill	410	30	28.0	382		
17	Slope	340	30	29.4	311	Mesh	Well fails; brook water used.

[a] See Pl. III, in pocket. [b] Depth reported.

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Drilled wells in Ansonia, Conn.

Map No.	Owner.	Topographic position.	Elevation above sea level.	Depth.	Diameter.	Yield per minute.	Cost.
			Feet.	*Feet.*	*Inches.*		
8	Bergin	Hill	375	70	6	Good	
10	J. G. Tingley	Hill	400	.....	6	.....	$1.50 per foot.[a]
11	James Winn	Flat	320	.....	6	.....	
13	C. C. Ford	Hill	410	.....	6	.....	
14	McCrety	Hill	420	[b] 70	6	.....	
16	William Ellis	Hill	390	[b] 70	6	Low	

[a] Does not include cost of casing.
[b] Drilled from bottom of dug well 30 feet deep; 30 feet to rock; drilled about 1893.

BEACON FALLS.

POPULATION AND INDUSTRIES.

Beacon Falls is in the west-central part of New Haven County, on Naugatuck River. It is reached by the Naugatuck division of the New York, New Haven & Hartford Railroad and by the Derby division of the Connecticut Co.'s Electric Railway. It was separated from Bethany, Oxford, Seymour, and Naugatuck and incorporated in May, 1871. Its area is 10 square miles.

The population of Beacon Falls in 1910 was 1,160. In 1880, 1890, and 1900 it was 379, 505, and 623, respectively. The principal industries are agriculture and the manufacture of rubber boots and shoes, small hardware, and bronze panels.

TOPOGRAPHY.

Beacon Falls extends across the valley of Naugatuck River. The highest elevation is in the northwest corner of the town, where Toby's Rock Mountain reaches an elevation of 730 feet above sea level. The lowest elevation, about 110 feet, is at the point where the river crosses the south boundary. The valley floor is narrow and is less than 2 square miles in area. The slopes and the hills in the eastern half of the town are all wooded.

The Naugatuck passes through the middle of the town and receives all the drainage. It is joined at Beacon Falls village by Hocanum Brook which rises in the western part of Bethany.

WATER-BEARING FORMATIONS.

Bedrocks.—The Hoosac ("Hartland") schist and the Prospect and Thomaston granite gneisses (p. 9) underlie Beacon Falls and are exposed in bare cliffs on both sides of Naugatuck River as well as on the steep slopes in other parts of the town. The bedrocks are too dense to afford large water supplies, but moderate supplies can be

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obtained from wells which intercept water-bearing fissures in the rock. (See p. 17.)

Till.—The unconsolidated surface deposits in all the upland parts of the town consist of mixtures of gravel, sand, and bowlders with some clay or rock powder, which were laid down as the last glacial ice melted. The material as it occurs in these deposits is called till. It ranges in thickness from a few inches to 25 or 30 feet, and moderate supplies of water for domestic purposes are obtained from the shallow wells which penetrate it. (See p. 11.)

Stratified drift.—Sand and gravel are found in the valley at the village of Beacon Falls. (See Pl. III.) The thickness of the deposit is not shown by data collected in this locality, but in Waterbury and in Seymour similar deposits have thicknesses of more than 100 feet. (See p. 14.)

SURFACE-WATER SUPPLIES.

The factory of the Beacon Falls Rubber Shoe Co., at Beacon Falls, is operated almost entirely by water power. Steam engines have been installed for use in emergencies, but the river is seldom so low as to necessitate their use. A storage reservoir belonging to the Seymour waterworks is situated on the west border of the town northwest of Pines Bridge.

GROUND-WATER SUPPLIES.

Eight dug wells examined in Beacon Falls range in depth from 9 to 27 feet and average 17 feet. Depth to water ranges from 7 to 18 feet and averages 13 feet. Most of the wells in this town draw their supplies from the till. The yields are low but adequate for ordinary domestic needs. Few wells are situated in the stratified deposits because the Seymour water system extends up the valley and supplies that part of the town which is underlain by the stratified drift.

Data obtained in regard to four drilled wells are given in the table on page 45.

In all parts of the town except the area represented by the dotted pattern on Plate III, till or rock will be encountered at the surface, and owing to the general thinness of the drift, dug wells will generally reach or even penetrate the bedrock. Drilled wells must be expected to draw their supplies from the rock, and they are likely to be more economical than dug wells where the drift is less than about 10 feet. Dug wells 20 to 30 feet deep are likely to obtain supplies adequate for ordinary domestic needs (see p. 36), and where it is possible good results may be expected from the siphon equipment described on page 39.

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In the area underlain by stratified deposits (See Pl. III) drilled or deep-driven wells should furnish large supplies, but it is possible that impure water will be obtained if the wells are pumped hard, because the principal source of recharge is Naugatuck River.

PUBLIC WATER SUPPLIES.

There is no generally distributed public water supply, but a main which extends from the works of the Seymour Water Co. to Beacon Falls supplies part of the water used by the Beacon Falls Rubber Shoe Co. and a few houses in the immediate vicinity of the rubber mill.

RECORDS OF WELLS AND SPRINGS.

Information concerning wells and springs at Beacon Falls is given below. The map cited is Plate III, in pocket.

Drilled wells in Beacon Falls, Conn.

Map No.	Owner.	Topographic position.	Elevation above sea level.	Depth.	Diameter.	Yield per minute.
			Feet.	*Feet.*	*Inches.*	*Gallons.*
1	R. A. Rice	Flat	395	55	6	25
2	Arthur Faetch	Slope	360	50	6	4
7	Beacon Falls Rubber Shoe Co	Flat	270	90	6	.....
8	.....do	Slope	300	[a] 130	6	1.6

[a] 20 feet to rock.

Dug wells in Beacon Falls, Conn.

Map No.	Owner.	Topographic position.	Elevation above sea level.	Depth.	Depth to water.	Elevation of water table above sea level.	Cover.	Remarks.
			Feet.	*Feet.*	*Feet.*	*Feet.*		
3	Daniel Edwards	Hill	400	17.2	16.0	384	.....	Fluctuation, 12 feet.
5	.....	Slope	350	18.3	17.4	333	.....	Well fails.
6	.....	Slope	340	14.7	12.5	317	Closed	
9	.....	Flat	210	19.4	15.5	194	Open	
10	.....	Flat	240	16.3	11.2	229	Closed	
11	.....	Slope	220	9.0	6.0	214	Open	
13	.....	Slope	350	.....	.....	.....	Closed	
14	.....	Hill	350	27.3	18.2	332	Open	Well fails.
15	.....	Slope	240	16.9	7.8	232	Open	

Springs in Beacon Falls, Conn.

Map No.	Owner.	Topographic position.	Elevation above sea level.	Temperature.
			Feet.	° *F.*
4	Cornelius Munson	Flat	300	54
12	.....	Slope	215	.....

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MIDDLEBURY.

POPULATION AND INDUSTRIES.

Middlebury, in the northwestern part of New Haven County, is bordered by Woodbury, Watertown, Waterbury, Naugatuck, Oxford, and Southbury. It is reached by electric railway from Waterbury and Woodbury, which operates on a 15-minute schedule during the summer season and on an hourly schedule during the winter. The town was organized from parts of Woodbury, Southbury, and Waterbury and was incorporated in 1807. Its area is 19 square miles.

The population in 1910 was 836, or practically the same as a hundred years ago. The slight fluctuations in population from 1810 to 1910 are shown in the accompanying table. The principal industry is agriculture.

Population of Middlebury, Conn., 1810–1910.

Year.	Population.	Increase.	Decrease.	Year.	Population.	Increase.	Decrease.
		Per cent.	*Per cent.*			*Per cent.*	*Per cent.*
1810	847	.....	.....	1870	696	5	.....
1820	838	.....	1	1880	687	.....	1
1830	816	.....	3	1890	566	.....	18
1840	761	.....	7	1900	736	30	.....
1850	763	0.3	.....	1910	836	14	.....
1860	664	.....	13				

TOPOGRAPHY.

Middlebury is hilly but much less rugged than adjacent river towns. The relief is nearly as great but the slopes are more gentle and comparatively few of them present bare rock surfaces. The lowest elevation is on the east border of the town, where Welton Brook crosses the line at an elevation of about 350 feet above sea level. The highest elevation—900 feet—is between Middlebury Center and Quassapaug Lake. As indicated on Plate III, the slopes and narrow valleys are generally wooded, but the broad hilltops are for the most part cultivated.

The principal streams are Hop Brook, Long Swamp Brook, Meschapock Brook, Long Meadow Brook, and Eightmile Brook. These are all small streams, having their heads in Middlebury, and all discharge into Naugatuck River except Eightmile Brook, which empties into Housatonic River. The town is not thoroughly drained, as is indicated by the appearance on the map (Pl. III) of several swampy areas, and Long Meadow Pond and Quassapaug Lake. Quassapaug Lake is endowed with considerable natural beauty and it is utilized as a summer resort.

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WATER-BEARING FORMATIONS.

Bedrocks.—Middlebury is underlain by crystalline rocks which, on the basis of lithologic differences, have been separated by the Connecticut Geological Survey into two formations and named the Waterbury gneiss and the Thomaston granite gneiss (p. 9). Crystalline rocks are not porous enough to allow free circulation of ground water, and consequently wells drilled into them must depend for their supplies on water-bearing fissures which they may intercept. This accounts for the wide range in the yields of different wells and for occasional dry holes in close proximity to good wells. (See p. 17.)

Glacial drift.—The bedrocks are overlain by a mantle of glacial drift consisting of till (p. 10), with a very few local deposits of coarsely stratified sand and gravel. The thickness of the drift ranges from a few inches to 30 or 40 feet, and averages about 20 feet. The occurrence of water in unconsolidated deposits is discussed on page 11.

GROUND-WATER SUPPLIES.

The depth to water, as determined by measurements of 28 dug wells, ranges from 3 to 25 feet and averages 9 feet. The wells range in depth from 9 to 31 feet and average 17 feet. All of the dug wells examined are in till and five of them go dry during dry seasons, but in general their supplies are adequate for domestic needs.

Eight drilled wells were examined in this town, which range in depth from 47 to 558 feet and average 166 feet. The yields range from 1.5 to 20 gallons per minute.

RECORDS OF WELLS AND SPRINGS.

Data in regard to wells and springs are given in the accompanying tables.

Dug wells furnish good supplies for domestic purposes in all parts of the town where the thickness of the drift is more than about 10 feet. The amount of waer available depends to some extent on the thickness of the drift, and where this is less than about 10 feet it is likely to be more economical to drill into the rock. In many places it will be possible to use the siphon well described on page 39.

Good domestic supplies may be obtained from drilled wells ending in the rock, but large yields should not be expected from single wells. (See p. 17.)

The wells and springs are numbered on Plate III (map in pocket) as indicated in the first column of the table.

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Dug wells in Middlebury, Conn.

Map No.	Owner.	Topographic position.	Elevation above sea level.	Depth.	Depth to water.	Elevation of water table above sea level.	Cover.	Remarks.
			Feet.	*Feet.*	*Feet.*	*Feet.*		
1	.....	Hill.....	580	27.2	20.2	560	Closed....	
3	.....	Flat.....	540	13.4	8.0	532	Open.....	
4	.....	Hill.....	745	30.3	12.9	732	Open.....	Not used.
8	.....	Slope....	760	.....	7.0	753	Open.....	
10	.....	Hill.....	560	14.5	10.7	549	Open.....	Fails.
13	.....	Slope....	580	17.8	10.0	570	Open.....	
14	.....	Flat.....	560	11.5	3.5	556	Open.....	
15	.....	Flat.....	530	18.8	10.5	519	Closed....	
17	.....	Flat.....	500	10.0	5.0	495	Open.....	
18	.....	Flat.....	480	.....	3.0	477	Closed....	
19	.....	Flat.....	420	13.8	6.0	414	Open.....	
20	.....	Flat.....	400	14.7	9.4	391	Open.....	
21	.....	Slope....	680	9.9	4.6	675	Open.....	
22	.....	Hill.....	675	13.5	7.2	668	Open.....	Not used.
24	A. J. Abbott.....	Hill.....	740	31.0	15.0	725	Closed....	
25	.....	Hill.....	660	11.0	5.2	655	.....	
27	Nichol Ferrante....	Hill.....	710	20.1	8.4	702	Closed....	
28	Nichol Ferrante....	Hill.....	710	11.0	5.6	704	Closed....	
32	.....	Hill.....	840	29.9	25.3	815	Open.....	Fails.
33	.....	Hill.....	820	9.0	2.9	817	.....	
34	.....	Slope....	560	19.6	6.6	553	.....	
35	.....	Hill.....	520	31.4	19.6	500	Closed....	Fails.
36	.....	Flat.....	460	13.4	6.8	653	Open.....	Fails
37	.....	Slope....	500	12.0	10.5	489	Closed....	Not used.
38	.....	Flat.....	555	10.6	4.1	551	.....	
39	.....	Hill.....	660	15.8	8.7	651	Closed....	
40	.....	Slope....	710	16.2	11.9	698	Open.....	Fails.
41	.....	Slope....	710	9.0	3.7	706	Open.....	

Drilled wells in Middlebury, Conn.

Map No.	Owner.	Topographic position.	Elevation above sea level.	Depth.	Diameter.	Yield per minute.	Remarks.
			Feet.	*Feet.*	*Inches.*	*Gallons.*	
2	T. L. Atwood.....	Slope....	755	47	.....	.....	Use 500 gallons a day.
5	W. H. White.....	Slope....	760	186	6	20	6 gallons a minute was capacity of pump. Water stood at 27 feet below surface after 8 hours pumping.
6	W. H. White.....	Hill.....	800	158	6	1.5	Well abandoned after shooting.
11	Ford.....	Hill.....	840	.....	.....	.....	
12	Carter.....	Hill.....	825	.....	.....	.....	
16	Westover School.....	Flat.....	700	558	(a)	[b]1,000	Yield inadequate: well abandoned; drilled in 1907; cost $4,000.
23	D. M. Atwood.....	Slope....	700	82	6	4	
26	Wm. Davis.....	Hill.....	700	.....	6	.....	
29	Alida Allerton.....	Flat.....	800	115	6	2	
30	Alida Allerton.....	Flat.....	890	81	6	4	
31	H. C. Bronson.....	Flat.....	835	100	6	3	

[a] 10 inches to rock and 8 inches in rock. [b] Per day.

Springs in Middlebury, Conn.

Map No.	Topographic position.	Elevation above sea level.	Temperature.	Yield per minute.	Remarks.
		Feet.		*Gallons.*	
7	Top of slope.....	820	.....	Low.	Covered.
9	Slope.....	700	54	2	Piped across road to house but *not used.*

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NAUGATUCK.

POPULATION AND INDUSTRIES.

Naugatuck is in the northwestern part of New Haven County on Naugatuck River. It is reached by the Naugatuck division of the New York, New Haven & Hartford Railroad, which has stations at Naugatuck and Union City; by the Highland division of the same railroad, which has a flag station at Allerton Farms; and by the Derby division of the Connecticut Co.'s Electric Railway. The town was organized from parts of Waterbury, Bethany, and Oxford, and incorporated in May, 1844. It has an area of 17 square miles.

In 1910 the population was 12,722. The table presented below, which gives the population in each decade from 1850 to 1910, shows a rapid growth in recent years accompanying the growth of the city of Waterbury. The chief industries are agriculture and the manufacture of india-rubber goods, knit underwear, malleable iron, buttons, copper and brass plating, chemicals, gas and electric fixtures, and cut-glass ware.

Population of Naugatuck, Conn., 1850–1910.

Year.	Population.	Increase.	Year.	Population.	Increase.
		Per cent.			*Per cent.*
1850	1,720		1890	6,218	45
1860	2,590	51	1900	10,541	70
1870	2,830	9	1910	12,720	21
1880	4,272	51			

TOPOGRAPHY.

Naugatuck River passes through the middle of the town, receiving all the drainage, and this stream together with its tributaries, Long Meadow Pond Brook, Beacon Hill Brook, and Spring Brook, has deeply dissected the surface, producing an average relief of about 400 feet. The highest elevation—850 feet—is on Huntington Hill, in the southwest corner of the town. The lowest elevation is 170 feet, where Naugatuck River crosses the south boundary. The upper parts of the slopes and the lower hills are wooded, but the tops of the higher hills and the lower parts of the slopes are clear and to some extent cultivated.

WATER-BEARING FORMATIONS.

Bedrocks.—The rock formations which underlie Naugatuck are the Waterbury gneiss, the Hoosac ("Hartland") schist, and the Thomaston granite gneiss (p. 9). These are metamorphosed rocks of igneous and sedimentary origin, and are too dense to allow ground water to circulate freely, but they are cut by numerous fissures some of which contain water (p. 17).

Till.—In all the upland parts of the town till (p. 10) is the rock cover. It ranges in thickness from a few inches to 30 or 40 feet and

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has an average thickness of about 15 feet. The occurrence of wa in till is discussed on page 11.

Stratified drift.—Naugatuck Valley and the valley of Beacon H Brook contain deposits of sand and gravel. These deposits are n row but they may be as much as 100 feet thick in some places. T occurrence of water in stratified deposits is discussed on page 11.

SURFACE-WATER SUPPLIES.

Water power is used to a large extent by the mills and factories Naugatuck and Union City. Power dams are situated on Lo Meadow Pond Brook, Beacon Hill Brook, on the brook which flo through Union City, and on Naugatuck River. A small stora reservoir of the Naugatuck waterworks is situated just west of Uni City.

GROUND-WATER SUPPLIES.

Seventeen dug wells, which range in depth from 8 to 27 feet a and average 17 feet, show depths to water ranging from 2 to 26 fe and averaging 11 feet. One of these wells, near the top of Andre Hill at an elevation of about 650 feet above sea level (No. 9, Pl. II is subject to a fluctuation in the water level of about 17 feet, but has never been dry. All of these wells are in till, and only one of the is likely to fail in dry seasons. (See table, p. 51.)

In those parts of the town which are underlain by till good domest supplies may be obtained from dug wells, provided the till is mo than about 10 feet thick. Where the rock lies within about 10 feet the surface satisfactory dug wells are likely to be more expensive th drilled wells, and the chances of obtaining good supplies are probab better in drilling. Siphon wells (see p. 39) are successfully used alo Beacon Hill Brook and they could be used to advantage in other par of the town where dwellings are situated near drift-covered slope The stratified deposits in the valleys would yield large quantities water, but if they were subjected to heavy drafts their supply wou probably be replenished to some extent from Naugatuck River.

PUBLIC WATER SUPPLIES.

The Naugatuck Water Co., of which D. P. Mills is president an E. C. Barnum general manager, furnishes water to the city of Naug tuck. The works include seven reservoirs, as follows:

Naugatuck city reservoirs.	Capacity, in gallons.
Prospect reservoir	110,000,000
Long Hill Brook reservoir	1,500,000
New reservoir	500,000,000
Candy Brook reservoirs (2)	5,500,000
Distributing reservoir	7,000,000
High-service (Mulberry) reservoir	11,000,000
	635,000,000

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Water is delivered by gravity under a pressure of about 110 pounds, through 40 miles of mains, supplying a population of about 10,000. The average daily consumption is between one and two million gallons, three-fourths of which is used for manufacturing purposes. In cases of emergency, water is pumped from Beacon Hill Brook by means of a Dean pump (steam) into the distributing reservoir. No germicidal treatment is used. Charges are based on both meter and flat rates.

RECORDS OF WELLS.

Information concerning wells in Naugatuck is presented in the following table. The map referred to is Plate III, in pocket.

Dug wells in Naugatuck, Conn.

Map No.	Owner.	Topographic position.	Elevation above sea level.	Depth.	Depth to water.	Elevation of water table above sea level.	Cover.
			Feet.	*Feet.*	*Feet.*	*Feet.*	
2		Hill	520	21.2	13.9	506	
3		Flat	360	17.4	8.2	352	Open.
4		Slope	290	22.0	17.8	272	Closed.
5		Slope	225	23.0	21.0	204	
6		Flat	330	9.0	4.4	326	
7		Slope	660	[a] 14.0	2.5	657	Open.
8	W. E. Hunter	Flat	700	21.6	6.5	693	Closed.
9	W. E. Hunter	Slope	650	20.0	2.0	[b] 648	Closed.
10		Hill	330	16.7	9.0	321	Open.
11		Flat	360	17.5	13.1	347	Open.
12		Slope	455	21.5	20.5	434	Mesh.
13		Slope	500	12.0	10.0	490	Closed.
15		Slope	630	27.0	26.4	604	Open.
17		Slope	660	19.0	17.0	643	
18		Slope	375	8.5	5.0	370	Closed.
19		Slope	365	10.0	5.0	360	Closed.
20		Flat	330	[c] 12.8	11.8	318	Open.

[a] Well goes dry. [b] Fluctuation, 17 feet. [c] Well not used.

OXFORD.

POPULATION AND INDUSTRIES.

Oxford, in the northwestern part of New Haven County, is reached by the Highland division of the New York, New Haven & Hartford Railroad, which has a station at Towantic, and by highway from Seymour, which is on the Naugatuck division of the same railroad, and on the Derby division of the Connecticut Co.'s Electric Railway. Stevenson, on the Berkshire division of the New York, New Haven & Hartford Railroad, is one-third of a mile west of the western border and is the station and post office for that portion of the town. Oxford was taken from Derby and Southbury and incorporated in October, 1798. The area of the town is 33 square miles.

The population of Oxford in 1910 was 1,020. The following table gives the changes in population from 1800 to 1910, and shows that there was a gradual decline from 1830 to 1890, but a slight increase more recently. The principal industry is agriculture.

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Population of Oxford, Conn., 1800–1910.

Year.	Population.	Increase.	Decrease.	Year.	Population.	Increase.	Decrease.
		Per cent.	*Per cent.*			*Per cent.*	*Per cent.*
1800	1,410			1860	1,269		1
1810	1,453	3		1870	1,338	5	
1820	1,683	15		1880	1,120		1
1830	1,763	5		1890	902		1
1840	1,626		8	1900	952	5	
1850	1,564		4	1910	1,020	7	

TOPOGRAPHY.

Elevations in Oxford range from about 40 feet above sea level on Housatonic River at the south corner of the town to 890 feet on Woodruff Hill on the north boundary. The town is characterized by high, steep, wooded slopes, narrow valleys, and by the absence of level land.

Housatonic River and Eightmile Brook form parts of the west boundary. Little River passes through the middle of the town, parallel to Housatonic River, and the headwaters of Long Meadow Pond Brook reach into the northeast corner of the town. These streams with their tributaries drain almost the entire area. A small area along the east border is drained by a small brook which joins Naugatuck River at Pines Bridge in Beacon Falls.

WATER-BEARING FORMATIONS.

Bedrocks.—Oxford is underlain by crystalline rocks which, according to their lithologic characters, are recognized as three different formations. The most extensive of these is the Waterbury gneiss which underlies the west half of the town. The Hoosac ("Hartland") schist underlies all of the east half of the town except a small area in the southeast corner where the Thomaston granite gneiss appears (p. 9). These rocks are exposed at the surface on steep slopes throughout the town, and in the beds of most of the brooks. The occurrence of water in rocks of this character is discussed on page 17.

Glacial drift.—The prevailing rock cover in Oxford is till, which consists of unassorted bowlders, gravel, sand, and rock powder, deposited by the last retreating ice sheet. This formation is generally very thin and is irregularly distributed; but it is, nevertheless, the most important source of ground water in the town, although only shallow well and spring supplies are obtained from it. Stratified drift occurs only in small patches along Little River and in the valley of Eightmile Brook north of Quaker Farms, where several small eskers extend into the valley. These stratified deposits, on account of their limited extent, furnish only shallow, domestic supplies. (See p. 11.)

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SURFACE-WATER SUPPLIES.

Water power is developed on Eightmile Brook at Southford and near Quaker Farms and on Little River at Oxford. There are several unused power sites, some of which seem to have been permanently abandoned, on small brooks tributary to these streams. One of the reservoirs of the Seymour Water Co. is situated in this town.

GROUND-WATER SUPPLIES.

Sixty-one dug wells examined in Oxford range in depth from 7 to 37 feet and average 17 feet. Depth to water ranges from 2 to 22 feet and averages 9 feet—in 41 of these wells the depth to water is less than 10 feet. Practically all are in till, 10 are not used, and 4 are said to fail in dry seasons. Samples of water were examined by the methods described in Water-Supply Paper 151 with the following results:

Six springs were observed, all of which were small gravity springs. (See p. 55.)

Eight drilled wells have depths ranging from 52 to 600 feet and yields ranging from 1 to 40 gallons a minute. The average depth is 160 feet and the average yield is 12 gallons a minute.

Stratified deposits in Oxford are so limited in extent that they are of little importance in determining the location of wells. Good water for domestic supplies is available in all parts of the town. Where the drift is more than about 10 feet deep dug wells generally furnish desirable supplies, but where it is thinner better wells are likely to be obtained by drilling. Supplies larger than those ordinarily required for domestic purposes should not be expected from wells, because they are usually not available. But comparatively large supplies can be obtained from surface-water reservoirs, sites for which are numerous.

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RECORDS OF WELLS AND SPRINGS.

Information concerning wells and springs in Oxford is given in the following tables. The wells and springs are numbered on Plate III.

Dug wells in Oxford, Conn.

Map No.	Owner.	Topographic position.	Elevation above sea level.	Depth.	Depth to water.	Elevation of water table above sea level.	Cover.	Remarks.
			Feet.	*Feet.*	*Feet.*	*Feet.*		
1	.....	Slope...	605	20.6	13.0	592	Closed...	Not used.
2	.....	Slope...	630	14.4	6.6	623	Open...	Not used.
3	F. B. Wheeler....	Slope...	700	20.2	9.3	691	Open...	Fails.
6	.....	Slope...	455	10.6	4.5	450	Open...	
7	.....	Slope...	525	10.0	4.5	520	Open...	
8	.....	Hill.....	670	18.1	7.4	663	Open...	
9	Franklin Nichols..	Hill.....	620	21.1	16.0	604	Open...	
10	.....	Slope...	550	16.4	12.4	538	Open...	
11	.....	Hill.....	560	32.3	12.2	548	Open...	Not used.
12	.....	Flat.....	565	12.1	5.1	560	Open....	
13	.....	Slope...	660	.....	5.7	654	Open...	
14	Town well in Towantic.	Flat.....	640	7.9	2.0	638	Open...	Two houses supplied.
15	.....	Flat.....	500	9.2	4.8	495	Closed...	
17	.....	Slope...	570	22.6	8.3	562	Open...	
18	.....	Slope...	500	15.1	9.2	491	Open....	
21	.....	Flat.....	600	11.4	5.7	594	Open....	Falls.
22	B. T. Nash.....	Slope....	560	27.3	22.3	538	Open...	Fluctuation, 12 feet.
23	.....	Slope...	600	25.1	21.7	578	Open...	Falls.
24	.....	Hill.....	605	20.4	3.2	602	Open...	
25	.....	Hill.....	605	26.4	8.8	596	Open...	
26	.....	Slope...	550	8.2	2.9	547	Open...	
27	.....	Hill.....	610	13.6	5.1	605	Open...	
28	.....	Hill.....	600	32.6	13.8	586	Open...	
29	.....	Slope...	500	12.1	5.0	495	Open...	
30	J. B. Berry.....	Slope...	540	18.7	9.1	531	Open...	Not used.
31	.....	Hill.....	625	27.7	16.1	609	Closed...	Not used.
33	.....	Hill.....	610	15.1	7.2	603	Open...	
35	.....	Flat.....	360	8.5	5.0	355	Closed...	Not used.
37	.....	Flat.....	440	15.3	11.2	439	Closed...	
38	.....	Slope....	360	11.3	8.8	351	Lot.....	
39	.....	Flat.....	380	33.0	18.3	362	Open...	
40	.....	Slope...	350	16.6	14.2	336	Open...	Not used.
41	.....	Slope...	345	19.9	15.6	329	Open...	Falls.
42	.....	Slope...	380	27.2	21.1	359	Open....	
43	.....	Slope....	420	13.2	4.9	415	Open....	Not used.
44	.....	Slope...	460	10.6	6.3	454	Open...	
45	.....	Hill.....	500	12.4	5.3	495	.....	
46	.....	Slope...	495	7.7	3.2	492	Open...	
47	.....	Slope....	360	12.5	6.9	350	Open....	
48	.....	Flat.....	355	10.8	4.7	350	Open....	
50	.....	Flat.....	420	14.5	8.4	412	Open....	
51	.....	Slope....	660	29.2	15.2	645	Closed...	
52	.....	Slope....	510	11.3	6.7	503	Open....	
53	.....	Flat.....	295	9.6	4.6	290	Open....	
54	.....	Hill.....	550	37.0	18.8	531	Closed...	
55	.....	Slope....	98	22.1	19.4	79	Open....	
58	.....	Flat.....	60	32.0	.....	.....	Closed...	Depth given as reported.
59	.....	Hill.....	385	17.1	7.5	377	Closed...	Not used.
60	.....	Hill.....	560	11.9	4.9	555	Open....	
61	.....	Hill.....	570	20.2	7.4	562	Open....	
62	.....	Hill.....	600	17.9	8.2	592	Open....	
63	.....	Slope....	630	19.2	7.3	623	Open....	
64	.....	Flat.....	570	13.0	8.0	562	Open....	
65	.....	Slope....	400	13.7	5.2	395	Open....	
66	.....	Slope....	605	13.2	5.0	600	Open....	
68	.....	Slope....	530	17.8	11.8	518	Open....	
71	.....	Flat.....	360	11.8	9.0	351	Open....	Not used.
72	.....	Slope....	430	15.3	13.3	417	Open....	
73	.....	Slope....	380	12.4	6.1	374	Closed...	
74	.....	Slope....	270	12.6	7.0	263	Open....	
75	.....	Flat.....	200	19.6	16.6	183	Open....	
76	.....	Flat.....	200	22.6	13.5	186	Open....	

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Drilled wells in Oxford, Conn.

Map No.	Owner.	Topographic position.	Elevation above sea level.	Depth.	Diameter.	Yield per minute.	Remarks.
			Feet.	*Feet.*	*Inches.*	*Gallons.*	
16	M. J. Cassidy	Hill	520	55	6	1.5	
20	Catherine Frazer	Slope	495	52	6	1	2 feet to rock.
32	G. W. Cable	Hill	630	70	6	20	
34	R. L. Androus	Slope	470	58	6	40	20 feet to rock.
36	Mrs. Julia Sanford	Flat	370	140	8	17	10 feet to rock; 10-hour test for yield; well completed May, 1910; cost of well, $640.
49	Chas. Davis	Flat	385	175		4	100 feet to rock.
67	J. H. Hale	Hill	670	128	8	4	10 feet to rock; well completed Sept. 1, 1905; cost of well, $540.
69	C. M. Eckstrom	Mill	580	600		12	40 feet to rock; cost of well, $3,600.

Springs in Oxford, Conn.

Map No.	Owner.	Topographic position.	Elevation above sea level.	Temperature.	Yield per minute.	Remarks.
			Feet.	*° F.*	*Gallons.*	
4	F. B. Wheeler	Top of slope	720	57	[a] 0.5	
5	David B. Wheeler	Top of slope	690	56	[b] 3.0	
19		Slope	470		Low.	
56		Slope	80		Low.	
57		Slope	100			Delivered by siphon.
70		Flat	60			Do.

[a] Well goes dry. [b] Flow is constant.

SEYMOUR.

POPULATION AND INDUSTRIES.

Seymour is in the western part of New Haven County on Housatonic and Naugatuck rivers. It is reached by the Naugatuck division of the New York, New Haven & Hartford Railroad, and the Derby division of the Connecticut Co.'s Electric Railway. It was separated from Derby and incorporated in May, 1850. The area of the town is 15 square miles.

The population of Seymour in 1910 was 4,786, a substantial increase over 1900. The population from 1850 to 1910 is shown in the following table:

Population of Seymour, Conn., 1850–1910.

Year.	Population.	Increase.	Year.	Population.	Increase.
		Per cent.			*Per cent.*
1850	1,677		1890	3,300	42
1870	2,172	28	1900	3,541	7
1880	2,318	7	1910	4,786	35

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The principal industries are the manufacture of brass and copper goods, plush, hard-rubber goods, boring implements, edge tools, horseshoe nails, paper, telegraph cables, bicycle parts, and eyelets, an iron foundry, and agriculture.

TOPOGRAPHY.

Elevations in Seymour range from about 30 feet to 640 feet above sea level, the lowest elevation being at Housatonic River, in the southwest corner of the town, and the highest about a mile and a half north of that place, on Great Hill. Eastward from Great Hill the land slopes rapidly downward to Naugatuck River, where the elevation is about 40 feet above sea level, and then rises rapidly to 500 feet above sea level on the east border of the town. Most of the slopes are wooded but the hilltops are cultivated.

Housatonic River forms a part of the western border and receives the drainage from that part of the town. Naugatuck River, which flows through the town parallel to and about 2 miles from the east border, drains about two-thirds of the area.

WATER-BEARING FORMATIONS.

Bedrocks.—Hoosac ("Hartland") schist and the Prospect granite gneiss (p. 9) comprise the bedrocks of Seymour and they are exposed at the surface on many of the steep slopes throughout the town. The Prospect granite gneiss is cut by a nearly vertical diabase dike which is about 40 feet wide. This diabase appears at the surface in a line parallel to and just east of Naugatuck River and is locally called trap rock because of its similarity to the "trap rocks" of the Connecticut River valley. None of these rocks is capable of furnishing a large supply of water, but the water-bearing fissures, which are numerous in all of them, afford moderate supplies to wells (p. 17).

Till.—In all parts of Seymour except the narrow valleys of Housatonic River, Naugatuck River, and Bladens River, the rock is covered with unassorted sand, gravel, and bowlders of glacial origin. The maximum thickness of this material was not determined, but it probably does not exceed 30 or 40 feet and the average thickness is about 15 feet. Most of the domestic water supplies are obtained from shallow wells in the till (p. 10).

Stratified drift.—The stratified deposits found along Housatonic, Naugatuck, and Bladens rivers are narrow and discontinuous. Their occurrence throughout the Waterbury area suggests that they were deposited by the smaller tributary streams while the principal valleys were still filled with ice. The thickness of the fill in the middle of the valley is shown by the logs of wells Nos. 58 and 59 (p. 59), to be about 125 feet. The occurrence of water is discussed on pages 11 and 14.

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SURFACE-WATER SUPPLIES.

Bladens, Little, and Naugatuck rivers furnish power for mills and factories in Seymour. A mill at Squantuck obtains power from Fourmile Brook, and a dam in Naugatuck River about 2 miles south of Seymour diverts water into a power canal which leads to Ansonia. Some of the storage reservoirs of the Ansonia waterworks are situated in the southeast corner of the town.

GROUND-WATER SUPPLIES.

The depths of 49 dug wells in Seymour range from 6 to 45 feet and average 18 feet. The depth of the water table below the surface of the ground, as determined by measurements of 48 wells, ranges from 6 inches to 38 feet and averages 14 feet—in 20 wells it is less than 10 feet to water. Eight of the wells examined are subject to failure and six wells are not used.

Six small gravity springs were observed, two of which are regularly used.

The depths of four drilled wells range from 60 to 447 feet and average 210 feet. They yield from 1.5 to 90 gallons a minute and average 28 gallons. Two are used for domestic purposes, one for manufacturing, and one situated in a public park furnishes drinking water. (See table, p. 59.)

Ground water for domestic use can be obtained from dug wells in all parts of Seymour where the drift is more than about 10 feet thick, but where bedrock is less than that distance below the surface it is generally advisable to drill into the rock. Very shallow wells are not likely to be permanent and they are not desirable from a sanitary viewpoint.

Shallow wells in the stratified deposits are especially liable to contamination on account of the topographic positions of these deposits and on account also of the greater density of population in the valleys underlain with stratified beds than on the till-covered uplands. Drilled or driven wells ending in gravel below the level of the river would probably furnish large supplies, but a large part of the water from this source would come from Naugatuck River because a heavy draught would soon exhaust the supply furnished from the narrow and steep slopes adjacent to the river. Larger supplies than those ordinarily required for domestic purposes should not be expected from wells in this area, although some drilled wells have furnished comparatively large amounts.

PUBLIC WATER SUPPLIES.

Seymour is supplied with water by a private company, of which Mr. D. A. Blakeslee, of New Haven, is secretary and treasurer. Very little information was obtained in regard to the system. It was

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said merely that the system comprises two reservoirs, and 55 public and 8 private hydrants. The water is delivered by gravity under a pressure of 100 to 120 pounds, and is sold at a flat rate, except to manufacturers, who pay on a meter basis.

RECORDS OF WELLS AND SPRINGS.

Information concerning wells and springs in Seymour is presented in the following tables. The map cited is Plate III, in pocket.

Dug wells in Seymour, Conn.

Map No.	Owner.	Topographic position.	Elevation above sea level.	Depth.	Depth to water.	Elevation of water table above sea level.	Cover.	Remarks.
			Feet.	*Feet.*	*Feet.*	*Feet.*		
2	.....	Slope...	90	45.3	32.6	57	Open...	
3	.....	Flat.....	60	16.8	9.5	50	.....	
4	.....	Slope....	560	7.9	.5	559	Open....	
5	.....	Hill.....	650	185	5.7	644	Open....	
6	.....	Slope....	560	7.3	.9	559	Open....	Surface drainage entering when well was measured.
7	.....	Hill.....	495	15.3	7.5	487	Mesh....	
8	.....	Slope....	430	11.7	3.2	427	Open....	Fails.
9	.....	Slope....	460	17.6	9.2	451	Open....	
10	.....	Slope....	210	16.3	8.0	202	Mesh....	Not used.
11	.....	Flat.....	365	11.0	6.0	359	Open....	Not used.
12	.....	Slope....	520	9.8	3.3	517	Open...	Seldom used.
13	.....	Flat.....	495	14.1	12.5	482	Open...	Not used.
14	Wilson Duckley.	Hill.....	505	29.1	26.6	478	.....	Fails.
15	.....	Hill.....	525	20.0	12.2	513	Open ...	Unclean.
17	.....	Slope....	375	22.5	16.4	359	Open....	
18	.....	Hill.....	390	15.8	25.3	365	Open....	
19	.....	Hill.....	300	7.2	3.4	297	Open...	
20	.....	Slope....	260	16.1	13.6	246	Mesh....	
21	.....	Slope...	120	21.1	18.1	102	Lattice..	Fails.
22	.....	Flat.....	75	26.4	22.6	52	Open...	
23	.....	Flat.....	75	23.7	14.0	61	Open....	
24	.....	Hill.....	550	18.0	9.7	540	Closed..	
25	.....	Hill.....	520	18.4	15.2	505	Open....	
26	.....	Slope....	410	15.8	5.8	404	Open....	Fails.
29	.....	Slope....	280	10.6	3.2	277	Open...	Fails.
30	.....	Slope...	185	6.2	3.1	182	Mesh....	
31	.....	Flat.....	80	18.1	14.0	66	Mesh....	
32	.....	Slope....	500	20.8	20.2	480	Open....	
35	.....	Slope....	300	17.5	16.3	284	Open....	
36	.....	Slope....	265	24.0	22.0	243	Open...	
37	.....	Flat.....	220	18.1	17.2	203	Open...	
38	.....	Slope....	250	10.2	8.4	246	Open....	
39	.....	Flat.....	165	9.0	5.4	160	.....	
41	.....	Slope....	210	31.1	Dry.	.....	Closed ..	Dry June to December each year.
42	.....	Flat.....	185	20.1	13.5	171	Closed..	
43	.....	Flat.....	170	30.2	27.9	142	Mesh....	
44	.....	Flat.....	155	37 9.	30.6	124	Mesh....	Never less than 5 feet of water.
45	.....	Flat.....	120	42.6	38.5	81	Open....	
47	.....	Slope...	230	15.2	14.5	215	Open....	
48	.....	Slope....	235	10.3	6.8	226	Open....	
49	.....	Hill.....	270	19.9	12.1	258	Mesh....	
50	.....	Hill.....	380	9.0	5.2	375	Open...	
51	.....	Slope....	380	24.9	22.5	357	Open....	
52	.....	Hill.....	380	14.6	11.0	369	.....	
53	.....	Hill.....	400	20.9	19.9	380	Lattice..	Not used; pump city water from reservoir.
54	.....	Hill.....	390	15.9	14.2	376	.....	
55	.....	Slope...	340	7.0	2.0	338	.....	
56	.....	Slope....	360	21.0	21.0	339	.....	Dry 2 months every year.
57	.....	Slope....	320	26.6	26.0	294	.....	Dry 2 months every year; not used.

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Drilled wells in Seymour, Conn.

Map No.	Owner.	Topographic position.	Elevation above sea level.	Depth.	Diameter.	Yield per minute.	Remarks.
			Feet.	*Feet.*	*Inches.*	*Gallons.*	
33	Smith Holbrook	Hill	395	98		5	26 feet to rock.
34	Joel Chatfield	Slope	370	60	6	18	
58	Waterman Pen Co., H. P. and E. Day.	Flat	85	447	8	(a)	128 feet to rock; cost of well, $2,159.
59	Seymour	Hill	155	234	6	1.5	230 feet to rock; cost of well, $841.

a Yields 30 gallons at suction and 90 gallons at 70 feet.

Springs in Seymour, Conn.

Map No.	Owner.	Topographic position.	Elevation above sea level.	Temperature.	Yield per minute.	Remarks.
			Feet.		*Gallons.*	
1	Sidney Downs	Slope	80			Converted to well.
16		Foot of slope	400			Pumped by windmill.
27		Slope	305	57	1	Constant.
28		Slope	300			
40	Edmund Day	Slope	255	55		
46	Arethusa Spring Water Co.	Slope	187	50	2	

THOMASTON.

POPULATION AND INDUSTRIES.

Thomaston is in the southeastern part of Litchfield County, in the Naugatuck Valley. It is reached by the Naugatuck division of the New York, New Haven & Hartford Railroad, which has stations at Thomaston and Reynolds Bridge; by trolley from Terryville station on the Highland division of the same railroad, 1 mile to the village of Terryville, thence 3 miles by stage; by trolley from Waterbury hourly. The town was separated from Plymouth and incorporated in May, 1875. It has an area of 12 square miles.

The census reports show a very slow growth in population since the first enumeration in 1880, as indicated in the following table. In 1910 the population was 3,533. The principal industries are agriculture and the manufacture of clocks and watches, brass goods, cutlery, clock bells, etc.

Population of Thomaston, Conn., 1880–1910.

Year.	Population.	Increase.	Year.	Population.	Increase.
		Per cent.			*Per cent.*
1880	3,225		1900	3,300	1
1890	3,278	2	1910	3,533	7

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TOPOGRAPHY.

The highest elevation, 1,022 feet, is on Lattin Hill, near the north boundary of the town; the lowest—about 330 feet above sea level—is at the confluence of West Branch of Naugatuck River with Naugatuck River. These rivers occupy narrow valleys whose walls rise abruptly 400 to 500 feet and embrace practically the entire area of the town.

WATER-BEARING FORMATIONS.

Bedrocks.—The rock floor is comprised of Waterbury gneiss, Thomaston granite gneiss, and a small body of amphibolite. These are crystalline rocks (p. 9), very dense in texture, and consequently poorly suited to furnish large quantities of water. Owing, however, to the intense fracturing which they have undergone water-bearing fissures are sufficiently numerous to afford moderate supplies to drilled wells. The occurrence of water in rocks of this character is discussed on page 17.

Glacial drift.—Unstratified drift or till (p. 10) consisting of bowlders, gravel, sand, and rock powder constitutes the rock cover in all the upland parts of the town. (See Pl. III.) Its thickness ranges from a few inches at the edge of rock outcrops to 25 or 30 feet and in all the deeper parts water may be obtained from dug wells. Stratified drift occupies the lowland adjacent to the rivers, as shown on Plate III, and ranges in thickness from a few feet to about 50 feet. The occurrence of water in unconsolidated deposits is discussed on page 11.

SURFACE-WATER SUPPLIES.

Power is developed on Naugatuck River at Thomaston; and the Wigwam reservoir of the Waterbury waterworks is situated on West Branch of the Naugatuck in the northwest corner of the town.

GROUND-WATER SUPPLIES.

Eighteen dug wells were examined in Thomaston ranging in depth from 10 to 30 feet and averaging 19 feet. Depth to water in these wells ranges from 2 to 16 feet and averages 8 feet. Most of the dug wells are in till and some of them doubtless penetrate rock, but no reliable information on this point is available. The annual fluctuation of the water level in one well was reported to be 14 feet and in another 8 feet. None of the wells examined have recently been dry, and the water supplied by all has been adequate for domestic needs.

Nine drilled wells were visited, and these range in depth from 40 to 338 feet and average 132 feet. Their yields, as determined by the drillers as the wells were finished, range from one-fourth gallon to 15

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gallons a minute, and average 5 gallons. The depths to bedrock range from 3 to 48 feet and average 14 feet. The cost of drilling was in most cases $3.50 a foot, but for three of the wells the total cost was reported, as indicated in the table on page 62. A considerable amount of well drilling is being done in Thomaston, notwithstanding the fact that the public water supply is available.

PUBLIC WATER SUPPLY.

The Thomaston waterworks were built by the Thomaston Water Co., a corporation, in 1880. The supply is obtained from springs and delivered by gravity from an impounding reservoir. The area of the reservoir is 40 acres and its capacity is between 80,000,000 and 100,000,000 gallons. The pressure is 90 to 125 pounds. There are 269 service connections and 50 fire hydrants. The use of meters is optional with the consumers but compulsory for the railroad company and town buildings. Twenty-nine are now in use. The consumption is not known. The flat rates range from $2 to $10, and the income for 1912 was $6,906.28. Mr. F. R. Roberts is secretary-treasurer.

According to tests by the State Board of Health of six samples collected in 1904 the water supply of Thomaston has an average color of 30 parts per million and an alkalinity of 7 parts.[1]

RECORDS OF WELLS.

Information concerning the wells in Thomaston is presented in the following tables. The map cited is Plate III, in pocket.

Dug wells in Thomaston, Conn.

Map No.	Topographic position.	Elevation above sea level.	Depth.	Depth to water.	Elevation of water table above sea level.	Cover.	Remarks.
			Feet.	*Feet.*	*Feet.*		
1	Hill.....	925	22.3	7.3	918	Open.....	Lowest on Nov. 5, 1913; at that time contained 3 feet of water.
2	Slope.....	740	.....	10.0	730	Closed....	
3	Hill.....	810	10.7	5.0	805	Open.....	
4	Hill.....	920	20.3	7.1	913	Closed....	2.5 feet of water at lowest stage in 1913.
5	Slope.....	440	23.3	16.9	423	Closed....	
6	Slope.....	400	13.9	7.0	393	Open.....	
7	Hill.....	800	15.4	5.8	794	Closed....	Use 35 gallons a day.
8	Hill.....	965	24.6	2.1	963	Closed....	Not used.
9	Hill.....	900	41.0	10.0	890	Closed....	
10	Slope.....	795	14.0	5.8	789	Closed....	Not used.
11	Slope.....	675	23.6	14.3	661	Open.....	
12	Flat.....	480	14.1	7.9	472	Closed....	
22	Flat.....	480	16.0	6.9	473	Open.....	
24	Flat.....	410	14.0	8.5	401	Closed....	
25	Flat.....	370	19.3	17.0	353	Closed....	
26	Flat.....	390	17.5	13.8	376	Open.....	Not used.
27	Slope.....	460	10.0	2.0	458	Closed....	Supplies nine families; fluctuation, 8 feet.
28	Slope.....	360	30.0	7.2	353	Open.....	Fluctuation, 14 feet.

[1] Connecticut State Board of Health Ann. Rept. 1904, p. 225.

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Drilled wells in Thomaston, Conn.

Map No.	Owner.	Topographic position.	Elevation above sea level.	Depth.	Diameter.	Yield per minute.	Cost.	Remarks.
			Feet.	*Feet.*	*Inches.*	*Gallons.*		
13	Seth Thomas Clock Co.	Flat..	460	338	8	8	$1,766.....	3 feet to rock.
14	W. T. Woodruff.....	Slope.	580	330	8	6	$1,596.....	6 feet to rock; completed Dec. 1, 1913.
15	Louis Schiappicasse..	Flat..	400	87	6	15	$3.50 per foot	3 feet to rock.
16	Alfred Holm.....	Slope.	420	65	6	½	$3.50 per foot	8 feet to rock.
17	Robert Innes.....	Flat..	400	50	6	2	$3.50 per foot	4 feet to rock.
18	"Thomaston".....	Flat..	375	110	8	.....	.....	Presented by W. C. T. U.
19	Geo. Hosford.....	Flat..	400	40	6	1	$3.50 per foot	5 feet to rock.
20	.....do.....	Flat..	410	55.5	6	10	$3.50 per foot	14 feet to rock.
21	S. H. Goodman.....	Flat..	380	.....	8	.....	.....	48 feet to rock; incomplete.
24	R. S. Newton.....	Flat..	400	110	6	½	$395.....	33 feet to rock.

WATERBURY.

POPULATION AND INDUSTRIES.

Waterbury is in the northern part of New Haven County, in the Naugatuck Valley. It is reached by the Naugatuck and Highland divisions of the New York, New Haven & Hartford Railroad, which has stations at Waterbury and Waterville, and by the Meriden division of the same road, which has a station at Waterbury; by trolley from New Haven via Cheshire, and from New Haven and Bridgeport via Derby; by trolley from Woodbury, Middlebury, and Thomaston; by stage from Woodbury and Middlebury daily. The town was named in 1686. The town and city are consolidated and have an area of 29 square miles.

The population in 1910 was 73,141. The following table shows the changes in population from 1756 to 1913.

The principal industries are the manufacture of rolled and cast brass and copper, german-silver goods, lamp trimmers, boilers, buttons, clocks, watches, plated wire, pins, eyelets, and buckles, electric-light and telephone wire, machinery, chemicals, etc., and agriculture. The city is the center of the brass industry in this country.

Population of Waterbury, Conn., 1756–1913.

Year.	Population.	Increase.	Decrease.	Year.	Population.	Increase.	Decrease.
		Per cent.	*Per cent.*			*Per cent.*	*Per cent.*
1756.....	1,829	.....	.....	1850.....	5,137	40	.....
1774.....	3,536	93	.....	1860.....	10,004	95	.....
1782.....	2,240	.....	36	1870.....	13,106	31	.....
1790.....	2,937	31	.....	1880.....	20,270	55	.....
1800.....	3,256	11	.....	1890.....	33,202	64	.....
1810.....	2,874	.....	12	1900.....	51,139	54	.....
1820.....	2,882	.....	.....	1910.....	73,141	43	.....
1830.....	3,070	6	.....	1913.....	[a] 81,000	11	.....
1840.....	3,668	19	.....				

[a] Estimated.

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TOPOGRAPHY.

The town extends across Naugatuck Valley and its topography is characteristically troughlike. The highest elevation—920 feet above sea level—is in the extreme northeast corner, and the lowest, about 220 feet, is on the river where it crosses the south boundary. The valley floor ranges in width from a few hundred feet at the south line to about a mile in the middle of the town, and from its edges the walls rise abruptly to elevations of 600 and 700 feet above sea level.

Hancock Brook, Steel Brook, and Mad River join Naugatuck River within the town.

WATER-BEARING FORMATIONS.

Bedrocks.—Crystalline rocks of three varieties—Hoosac ("Hartland") schist, Waterbury gneiss, and Thomaston granite gneiss, (p. 9)—comprise the bedrocks underlying the town. These rocks appear at the surface on the steep slopes in the south and east parts of the town and, except in the bottom of the valley, they are nowhere thickly covered by drift. The occurrence of water in crystalline rocks is discussed on page 17.

Glacial drift.—In the upland parts of Waterbury the rock cover consists of till or bowlder clay (p. 10) ranging in thickness up to 75 feet or more. On the flat lands along Naugatuck River the deposits are stratified and reach a thickness of over 100 feet in some places, as indicated by the log of a well drilled in the middle of the valley just south of the city, which reached bedrock at a depth of 111 feet below the surface. (See No. 5, p. 67.) The distribution of stratified and unstratified drift is shown on Plate III. The occurrence of water in unconsolidated deposits is discussed on page 11.

SURFACE-WATER SUPPLIES.

Water power is used in manufacturing plants on Naugatuck and Mad rivers. Several reservoirs belonging to the city waterworks are in the town east of the river, as indicated on the map (Pl. III).

GROUND-WATER SUPPLIES.

The average depth of the water table below the surface of the ground, as determined by measurement of 22 representative dug wells, is 13 feet. (See table, p. 66.) These wells range in depth from 7.1 to 39.9 and average 20 feet, the depth to water ranging from 3.5 to 32.2 feet. The annual fluctuation of the water table in one of the wells was reported to be about 13 feet. The average fluctuation, however, probably does not exceed 8 feet, taking into consideration the lowland areas in which changes in ground-water levels are relatively small.

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Eight drilled wells that were examined range in depth from 55 to 550 feet and average 175 feet. The yields reported for six of these range from 4 to 60 gallons a minute and average 16 gallons. Detailed information in regard to these wells is tabulated on page 67.

The city water system extends to nearly all parts of the town and consequently there is little need for private dug wells. Drilled wells, however, are used by manufacturing companies to furnish water for drinking and for some special purposes in manufacturing, and they are used also in some parts of the city at higher elevations than those at which city water is effectively delivered. All wells are drilled into bedrock, even those located in the river valley, where the stratified stream deposits are more than 100 feet thick.

No attempt is made to obtain supplies from the drift itself because the till deposits are too thin and compact to furnish adequate supplies, and it is the popular belief that the water in the gravels near the river is contaminated. The problem of utilizing the underflow of the Naugatuck Valley is discussed on page 23.

Analyses of the water of three drilled wells in Thomaston are given in the subjoined table; the numbers refer to the descriptions of the wells in the record on pages 66 and 67. Comparison of the analyses illustrates the difference in composition likely to be encountered in ground waters from fractured crystalline rocks.

Analyses of water from drilled wells in Thomaston.

[Parts per million. Samples collected June 24, 1915; R. B. Dole, analyst.]

No. on map.[a]	Iron (Fe).	Carbonate radicle (CO_3).	Bicarbonate radicle (HCO_3).	Sulphate radicle (SO_4).	Chlorine (Cl).	Total hardness as $CaCO_3$.	Total solids at 180° C.
15	2.9	0.0	4.9	44	42	94	[b] 292
19	.2	.0	48	34	8.2	84	169
20	1.5	.0	18	20	6.8	33	99

[a] See Plate III, in pocket; also record of wells on p. 66. [b] Much organic matter present.

PUBLIC WATER SUPPLY.

The city engineer reported that the works include three reservoirs, two of which, Wigwam and Morris reservoirs, on West Branch of Naugatuck River, have areas of 105 and 150 acres and capacities of 750,000,000 and 2,000,000,000 gallons, respectively. The water is supplied to about 70,000 people, the average daily consumption being about 7,500,000 gallons. The Morris reservoir was begun in 1909 and was practically complete at the close of 1913. (See Pl. III.)

The average condition of the water of Fenn and Morris brooks at Waterbury is indicated in the following table, which gives the averages of tests of 36 samples from each source examined by the State Board of Health between 1898 and 1901.

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Average quality of surface waters near Waterbury.[a]

[Parts per million.]

Source.	Color.	Total solids at 100° C.	Organic and volatile matter.	Total hardness as $CaCO_3$.	Chlorine.
Fenn Brook	43	48	14	11	1.7
Morris Brook	32	48	13	15	2.3

[a] Compiled from annual reports of the State Board of Health of Connecticut, 1898–1901.

According to Baker[1] the Waterbury waterworks were built by the city in 1868, and an additional supply was introduced in 1895. The supply is obtained from East Mountain Brook and West Branch of Naugatuck River. For the fiscal year ending December 31, 1895, there is reported 38 miles of mains, 4,023 taps, 270 meters, and 230 public and 50 private hydrants; and the consumption is given as 4,000,000 gallons.

The census report for 1911 gives the following financial data for 1911:

Revenue receipts	$203,952
Payments for expense	32,133
Payments for outlays	320,624
Value of land, building, and equipment	2,791,720
Debts incurred	1,560,000

The following statement in regard to future developments is quoted from the annual report of the city engineer of the city of Waterbury for the year 1912 (p. 26):

During the winter of 1911–12 some surveying was done on a proposed reservoir above the one (Morris) now being constructed. It was determined that such a reservoir could be made in the valley of Pitch Brook, which with a depth of water of 90 feet would store about 1,200,000,000 gallons and have an area of about 100 acres.

Borings were made at an assumed site for a dam, and ledge was located all across the valley. Conditions favor the same type of construction as is being used at Morris dam. These surveys will probably be completed this winter and more accurate information obtained.

During the past year the city has again very narrowly escaped a water famine, necessitating restrictions which were highly uncomfortable and inconvenient. Fortunately the immediate future will be free from these unpleasant experiences due to the bringing into use of Morris reservoir. The question to be considered, however, is for how long this increased supply will continue to be ample, and whether the construction of still another storage reservoir ought not to be undertaken in 1914, immediately after the completion of this one.

In a report to the board of aldermen, dated October 7, 1912, by a committee appointed by that body, figures were presented showing conclusively that the West Branch watershed could fill another such reservoir, even in a year of minimum rainfall. It was also pointed out that the city was growing rapidly; that the consumption of water would increase from other causes as well as on account of such

[1] Baker, N. M., The manual of American waterworks, p. 83, 1897.

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growth; that it was very important for Waterbury to have reservoir capacity some years ahead of its actual needs and that the construction of reservoirs, including preliminary engineering studies, the removal of legal obstacles, etc., takes several years.

The conclusion reached by the committee was that a third reservoir on the West Branch watershed could wisely be undertaken as soon as Morris reservoir is completed. If such construction is to begin in 1914, it will be necessary to undertake the preparation of plans early in the coming year.

Assuming that three reservoirs are built on the West Branch with a combined storage of nearly 4,000,000,000 gallons, the city will have reached the limit of development on that watershed. It will then be necessary to obtain water from some other source. For various reasons it appears likely that the obtaining of rights to take water from new sources will hereafter be found increasingly difficult. It would be wise for Waterbury to give early attention to this matter and secure such rights now, without waiting until urgent necessity compels the acceptance of burdensome and expensive conditions.

RECORDS OF WELLS AND SPRINGS.

Information concerning the wells in Waterbury is presented in the following tables. The map referred to in the first column is Plate III, in pocket at end of volume.

Dug wells in Waterbury, Conn.

Map No.	Owner.	Topographic position.	Elevation above sea level.	Depth.	Depth to water.	Elevation of water table above sea level.	Cover.	Remarks.
			Feet.	*Feet.*	*Feet.*	*Feet.*		
1	.....	Slope....	600	28.7	4.3	596	Open....	
2	.....	Slope....	530	.....	9.0	521	.....	
7	.....	Hill.....	570	.....	10.5	559	Open....	
10	.....	Slope....	525	12.0	3.7	521	Open....	Not used.
14	.....	Slope....	555	13.4	12.4	543	Open....	Not used.
15	.....	Flat.....	570	.....	9.8	560	.....	
16	.....	Hill.....	570	24.7	20.0	550	Open....	Not used.
17	.....	Hill.....	900	13.0	4.9	895	Closed..	
18	.....	Slope....	730	19.0	8.0	722	.....	Fluctuation 13 feet; falls.
19	.....	Slope....	655	13.7	5.5	649	.....	
21	.....	Slope....	475	20.4	9.1	486	Open....	
22	.....	Flat.....	500	7.1	3.5	496	Closed...	
23	.....	Slope....	600	15.2	9.8	590	Open....	
24	.....	Slope....	500	11.8	6.5	493	.....	
25	.....	Hill.....	520	24.9	22.5	497	.....	
26	.....	Slope....	520	27.2	22.0	498	.....	Not used.
27	.....	Slope....	450	21.2	15.5	434	Open....	
28	.....	Slope....	515	39.9	29.5	485	Lattice..	
29	.....	Hill.....	490	25.0	18.6	473	Closed...	Not used.
30	G. H. Reed.....	Slope....	530	14.8	4.0	526	Closed...	
32	.....	Slope....	300	30.1	24.9	275	Closed...	Not used.
33	.....	Slope....	260	33.5	32.2	228	Lattice..	

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Drilled wells in Waterbury, Conn.

Map No.	Owner.	Topographic position.	Elevation above sea level.	Depth.	Diameter.	Yield per minute.	Cost.	Remarks.
			Feet.	*Feet.*	*Inches.*	*Gallons.*		
4	Chas. Doll	Slope	670	59	6	5		22 feet to rock.
5	Manufacturer's Foundry Co.	Flat	260	166	8	60	[a] $5	111 feet to rock.
6	Chas. Reed	Slope	670	63	6	4		
8	Henry Joy	Hill	560	55	6	7		
9	John Joy	Hill	540		6			
11	Waterbury Country Club.	Hill	560	550(?)				
12	R. A. Judd	Slope	540	200(?)	6			
13	Harry Waterworth	Flat	535	91	6	12		75 feet to rock; water pumped from 80 feet below surface.
20	Perkins	Slope	400	216	6	8		8 feet to rock; 14 feet of casing used.

[a] Per foot.

Springs in Waterbury, Conn.

Map No.	Owner.	Topographic position.	Elevation above sea level.	Yield per minute.	Remarks.
			Feet.	*Gallons.*	
3		Slope	560	(a)	
31		Slope	515	4	Covered; supplies horse trough.

[a] Constant.

WATERTOWN.

POPULATION AND INDUSTRIES.

Watertown is in the southeastern part of Litchfield County, in the Naugatuck River valley. It is reached by the Watertown branch of the Naugatuck division of the New York, New Haven & Hartford Railroad, which has stations at Oakville and Watertown, and by trolley from Waterbury. Post offices are maintained at Oakville and Watertown. It was separated from Waterbury and incorporated in 1780. The area of the town is 30 square miles.

The population in 1910 was 3,850. The changes in population from 1782 to 1910 are shown in the following table. The principal industries are agriculture and the manufacture of silk thread, umbrella trimmings, mouse traps, and general hardware.

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Population of Watertown, Conn., 1782–1910.

Year.	Population.	Increase.	Decrease.	Year.	Population.	Increase.	Decrease.
		Per cent.	*Per cent.*			*Per cent.*	*Per cent.*
1782	2,732			1850	1,533	6	
1790	3,170	16		1860	1,587	4	
1800	1,622		49	1870	1,698	7	
1810	1,714	6		1880	1,897	12	
1820	1,439		16	1890	2,323	23	
1830	1,500	4		1900	3,100	33	
1840	1,442		4	1910	3,850	24	

TOPOGRAPHY.

Elevations in Watertown range from about 280 feet to a little over 1,000 feet above sea level. The lowest point is on Naugatuck River in the southwest corner of the town, and the highest is in the northwest corner, about 1 mile north of Big Meadow Pond. The hilly character of the town and the distribution of woods is shown on Plate III.

Naugatuck River and its west branch, which form the east boundary of the town, receive all the drainage except that from a small area in the northwest which contains the headwaters of Pomeraug River.

WATER-BEARING FORMATIONS.

Bedrocks.—Crystalline rocks of two varieties—Waterbury gneiss and Thomaston granite gneiss (p. 9)—compose the rock floor of Watertown. They are very dense in texture and consequently poorly suited to furnish large quantities of water. But they have been intensely fractured, and fissures which contain water are sufficiently numerous to afford moderate supplies to drilled wells. The occurrence of water in crystalline rocks is discussed on page 17.

Glacial drift.—Till constitutes the rock cover in all parts of the town except a narrow strip along Naugatuck River where the stream deposits are found. Till consists of mixtures of clay, sand, gravel, and bowlders, and was deposited by the retreating ice sheets at the close of the glacial epoch. In some places the till is about 100 feet thick, but in other places, as shown on Plate III, the bedrocks are exposed. (See p. 11.)

GROUND-WATER SUPPLIES.

Forty-six dug wells, ranging in depth from 6 to 29 feet and averaging 16 feet, were examined. Depth to water in these wells ranges from 2 to 23 feet and averages 7 feet. All the wells pass through till but at least three end in rock. Only four were reported to go dry, although seven of those examined have been abandoned.

Springs are numerous along the brooks and hillsides throughout the town, but they are all gravity springs of low yield and the usual

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method of utilizing the flow is to dig a shallow well and install a pump or siphon. There has been little drilling in Watertown heretofore, but it is said that a considerable amount of this work is contemplated. A 6-inch well drilled for Albert Blakesley to a depth of 118 feet yields 2 gallons a minute. It is situated at an elevation of about 880 feet above sea level and reached bedrock at 96 feet below the surface. The records of drilled wells in other towns of this area will serve to indicate the prospects for drilled wells in Watertown, since the occurrence of water is uniform throughout the area.

The following analysis represents a moderately mineralized but rather hard water containing almost no iron:

Analysis of water from dug well of J. H. Atwood, Watertown, Conn.

[Sample collected June 24, 1915. No. 36 in record table (p. 70). R. B. Dole, analyst.]

	Parts per million.
Silica (SiO_2)	10
Iron (Fe)	Trace.
Calcium (Ca)	32
Magnesium (Mg)	5
Carbonate radicle (CO_3)	.0
Bicarbonate radicle (HCO_3)	60
Sulphate radicle (SO_4)	25
Chlorine (Cl)	48
Total hardness as $CaCO_3$	120
Total solids at 180° C	291

PUBLIC WATER SUPPLY.

The Watertown Water Co., of which A. W. Wheeler is superintendent, supplies the village of Watertown. The works include an impounding reservoir in Bethlehem, 22 feet deep, with a capacity of 20,000,000 gallons, and a distributing reservoir holding 500,000 gallons. Water is delivered by gravity through 13 miles of mains under pressures of 40 to 135 pounds. There are 53 hydrants belonging to the fire district, 4 private hydrants, and 278 service connections. There about 2,500 consumers and the average daily consumption is estimated to be 250,000 gallons. The following financial statement was furnished:

Total cost of construction, estimated	$68,000
Cost of operation, estimated	2,361
Gross income	6,200

Four meters are in use, the rate being 10 to 40 cents per 1,000 gallons, but most of the supply is furnished at a flat rate, $8 a year being the minimum charge.

It is said that the present supply is inadequate and that it is occasionally necessary to pump water into the mains from brooks. A supply several times as large as that now available is needed.

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According to tests made by the Connecticut State Board of Health of 12 samples from the city reservoir in 1901 the water supply has an average color of 57 parts per million, a total hardness of 20 parts, and an alkalinity of 23 parts and contains 63 parts of total solids, of which 25 parts is volatile matter.[1]

RECORDS OF WELLS AND SPRINGS.

Information concerning the wells and springs in Watertown is given in the following tables. The map cited is Plate III.

Dug wells in Watertown, Conn.

Map No.	Owner.	Topographic position.	Elevation above sea level.	Depth.	Depth to water.	Elevation of water table above sea level.	Cover.	Remarks.
			Feet.	*Feet.*	*Feet.*	*Feet.*		
2	.....	Slope....	910	14.1	6.6	903	Closed...	
5	E. H. Peck...	Hill.....	790	19.7	2.8	787	Open....	Falls.
6	.....	Slope....	770	6.6	.9	769	Closed...	
7	.....	Slope....	785	15.6	12.9	772	Open....	
8	.....	Slope....	660	17.2	5.3	655	Closed...	
9	.....	Slope....	750	14.8	4.7	745	Closed...	
12	.....	Hill.....	910	12.8	3.2	907	Closed...	Not used.
13	E. B. Atwood.	Slope....	890	10.2	4.5	885	Closed...	
15	.....	Flat.....	840	15.5	2.1	838	Closed...	Not used; falls.
16	.....	Hill.....	860	26.8	3.0	857	Closed...	
17	M. J. Scott....	Slope....	780	.....	7.3	773	Open....	
18	"Ruby Farms"	Slope....	670	.....	12.0	658	Closed...	
20	.....	Slope....	550	13.9	2.9	547	Closed...	Not used.
21	.....	Slope....	740	11.6	3.0	737	Open....	
24	.....	Hill.....	880	19.4	13.5	866	Closed...	17 feet to rock.
27	.....	Slope....	840	.....	8.0	832	Closed...	Depth to water reported.
28	.....	Slope....	700	7.0	.....	.....	Closed...	
29	.....	Hill.....	750	18.0	14.0	736	.....	14 feet to rock.
30	.....	Slope....	440	25.0	23.0	417	.....	
32	.....	Slope....	550	15.5	8.4	542	Closed...	
33	.....	Hill.....	685	.....	8.0	677	.....	
34	.....	Hill.....	670	.....	8.7	661	.....	
35	.....	Slope....	550	11.9	5.0	545	Open....	Falls.
36	J. H. Atwood.	Hill.....	760	18.9	8.7	751	Open....	
38	.....	Hill.....	590	22.0	6.0	584	Closed...	
39	.....	Slope....	740	18.0	4.7	735	Closed...	
40	.....	Slope....	680	16.3	9.3	671	Closed...	
41	.....	Hill.....	700	25.1	7.1	693	Closed...	
42	.....	Slope....	640	.....	5.8	634	Closed...	Use city water.
44	.....	Slope....	540	9.3	4.1	536	Open....	
45	.....	Hill.....	605	16.1	8.7	596	Closed...	
48	.....	Hill.....	650	18.0	13.0	637	Closed...	
49	.....	Slope....	585	29.0	17.0	568	.....	
50	.....	Hill.....	765	17.7	5.6	759	Closed...	
52	.....	Hill.....	740	.....	12.0	728	.....	
53	.....	Hill.....	660	11.6	6.0	654	Closed...	11 feet to rock.
55	.....	Slope....	560	16.7	10.1	550	Closed...	Not used.
58	.....	Flat.....	755	17.7	11.5	743	Open....	Not used.
59	.....	Hill.....	680	.....	8.0	672	.....	
63	.....	Slope....	710	11.4	3.8	706	Closed...	
64	.....	Slope....	680	7.0	4.0	676	Closed...	8 feet square.
65	.....	Flat.....	590	10.9	7.2	583	Open....	
66	.....	Slope....	640	7.0	3.0	637	Closed...	
67	Thomas Lillis.	Slope....	625	12.5	3.7	621	.....	Falls.
68	.....	Flat.....	530	.....	7.0	523	Closed...	
69	.....	Slope....	570	17.6	9.0	561	.....	Not used.
71	.....	Slope....	620	17.5	7.5	612	Closed...	Not used.

[1] Connecticut State Board of Health Ann. Rept., 1901, p. 263.

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Drilled wells in Watertown, Conn.

Map No.	Owner.	Topographic position.	Elevation above sea level.	Depth.	Diameter.	Yield per minute.	Remarks.
			Feet.	*Feet.*	*Inches.*	*Gallons.*	
23	Albert Blakesley	Hill	880	118	6	2	96 feet to rock.
46	Preston	Slope	560				
47	Chas. Abbott	Slope	440				

Springs in Watertown, Conn.

Map No.	Owner.	Topographic position.	Elevation above sea level.	Temperature.	Yield per minute.	Remarks.
			Feet.		*Gallons.*	
1		Top of slope	920			Delivered to barn by ram.
3		Slope	755		[a] 2.5	
4		Slope	920		[a] .5	Not used; covered.
10		Top of slope	800	54	[b] 3.0	
11		Slope	800		1	Not used; covered.
14	E. B. Atwood	Foot of slope	800		2	
19		Foot of slope	685			
22		Slope	645			Covered.
25		Slope	850			
26		Foot of slope	880			5 feet deep; 0.8 foot to water; used.
31		Foot of slope	470		.5	Used.
37	J. H. Atwood	Foot of slope	755		[a] 1.0	
43		Foot of slope	655		.5	Not used; covered.
51		Slope	685	54	[b] .5	Open.
54		Slope	610			
56	Richenbach	Slope	725		(b)	Delivered to house and barn by gravity through 1,500 feet of pipe.
57		Top of slope	795		[a] Low.	Delivered to house and barn by siphon.
60		Foot of slope	615			No overflow.
61		Slope	675		(a)	
62		Slope	715		3	
70		Slope	660			

[a] Yield constant. [b] Yield varies.

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INDEX.

	Page.
Amphibolite, description of	10
Analyses of waters	64, 65, 69
Ansonia, description and industries of	39–40
ground-water supplies in	41
public water supply of	41–42
records of wells in	42–43
surface-water supplies in	40
water-bearing formations in	40
Ansonia Water Co., works of	42
Beacon Falls, description and industries of	43
records of wells and springs in	45
sources of water in	43–45
Brookline, Mass., municipal pumping plant at	24–26
Brooklyn, N. Y., municipal pumping plant at	26
Circulation of ground water	11–12
Crystalline rock with water-bearing fissures, plate showing	18
water in	17
Diabase, description of	10
Domestic water supply, springs as sources of	29
wells as sources of	29, 30–31
Drainage, underground	11–12
Evaporation, amount of	14–15
Forbes, F. F., on the municipal pumping plant at Brookline, Mass	24–26
Fountain Water Co., territory of	41
Geography of the Waterbury area	7–9
Geology of Waterbury	9–10
Glacial drift, description of	10
Hartland schist, description of	9
Hoosac schist, description of	9
Infiltration galleries, construction of	35–36
uses of	23
Middlebury, description and population of	46
records of wells and springs in	47–48
sources of water in	47
Municipal water supply, quality needed in	19
quantity required for	18–19
sources of	20–28
Naugatuck, description and population of	49
public water supply of	50–51
records of wells in	51
sources of water in	49–50
Naugatuck River valley, driven wells in	23
Orange phyllite, description of	9
Oxford, description and population of	51–52
records of wells and springs in	54–55
sources of water in	52–53
Plainfield, N. J., municipal pumping plant at	27–28
Porosity of the unstratified drift	11
Prospect granite gneiss, description of	9
Rainfall, record of	10
Run-off, sources of	14–17
Seymour, description and population of	55–56
public water supply of	57–58
records of wells and springs in	58–59
sources of water in	56–57
Springs, yield of water from	21
Storage basins, underground	16–17
Stratified deposits, plates showing	10, 18
Streams, municipal water supply from	20–21
Thomaston, analyses of well waters from	64
description and population of	59–60
public water supply of	61
records of wells in	61–62
sources of water in	60–61
Thomaston granite gneiss, description of	9
Till-covered area, plate showing	10
Tribus, L. L., on the municipal pumping plant at Plainfield, N. J	27–28
Water table, position of	12–13
Waterbury, population and industries of	62
public water supply of	64–66
records of wells and springs in	66–67
sources of water in	63–64
topography of	63
Waterbury area, map of	In pocket.
Waterbury gneiss, description of	9
Watertown, description and population of	67–68
public water supply of	69–70
records of wells and springs in	70–71
sources of water in	68–69
Wells, drilled, construction of	31
drilled, cost of	32
improvement of	33
quality of water from	32
water supplies from	21–22
driven, construction of	33–35
municipal water supply from	23–28
quality of water from	35
dug, construction of	36–39
water supplies from	22–23

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DEPARTMENT OF THE INTERIOR
FRANKLIN K. LANE, Secretary

UNITED STATES GEOLOGICAL SURVEY
GEORGE OTIS SMITH, Director

WATER-SUPPLY PAPER 398

GROUND WATER
IN
SAN JOAQUIN VALLEY, CALIFORNIA

BY

W. C. MENDENHALL, R. B. DOLE
AND HERMAN STABLER

WASHINGTON
GOVERNMENT PRINTING OFFICE
1916

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CONTENTS.

	Page.
Introduction, by W. C. Mendenhall	9
Development of irrigation in the Southwest	9
Investigations by the United States Geological Survey	13
Geography of the valley	15
Geologic outline	18
Rocks of the border of the valley	18
Origin of the present surface of the valley	20
Soils	22
Surface waters	23
Occurrence and utilization of ground water, by W. C. Mendenhall	27
Origin of the ground water	27
Underground circulation	28
Quantity of ground water	29
Accessibility and availability of ground water	30
Development of ground water	30
Value of the waters for irrigation	32
Quality of the waters, by R. B. Dole	38
Importance of quality	38
Sources of data	39
Conditions of collection of samples	40
Methods of examination	41
Field assay	41
Carbonate and bicarbonate	42
Chlorine	42
Sulphate	42
Total hardness	43
Probable accuracy	43
Interpretation of results	46
Procedures of the Southern Pacific Co	50
Standards for classification	50
Mineral constituents of water	50
Water for irrigation	51
Source of alkali	51
Occurrence of alkali	52
Permissible limits of alkali	52
Relative harmfulness of the common alkalies	55
Relation between applied water and soils	55
Numerical standards	56
Remedies for alkali troubles	58
Washing down the alkali	58
Drainage	60
Miscellaneous remedies	61

Digitized by Google

Quality of the waters—Continued.
Standards for classification—Continued. Page.
Water for boiler use ... 61
Formation of scale ... 61
Corrosion ... 62
Foaming ... 63
Remedies for boiler troubles ... 63
Boiler compounds ... 64
Numerical standards ... 65
Water for miscellaneous industrial uses ... 69
General requisites ... 69
Effects of dissolved and suspended materials ... 69
Free acids ... 70
Suspended matter ... 70
Color ... 70
Iron ... 70
Calcium and magnesium ... 71
Carbonate ... 72
Sulphate ... 72
Chlorine ... 72
Organic matter ... 73
Hydrogen sulphide ... 73
Miscellaneous substances ... 73
Water for domestic use ... 73
Physical qualities ... 73
Bacteriologic qualities ... 74
Chemical qualities ... 75
Mineral matter and potability ... 76
Interpretation of field assays in relation to potability ... 79
Chemical character ... 79
Total solids ... 81
Purification of water ... 82
General requirements ... 82
Methods of purification ... 83
Slow sand filtration ... 84
Rapid sand filtration ... 86
Cold-water softening ... 87
Feed-water heating ... 88
Chemical composition of the surface waters ... 90
Rivers ... 90
Tulare Lake ... 94
Buena Vista reservoir ... 96
Denudation and deposition ... 97
Rate of denudation in the Sierra ... 97
Rate of deposition in the valley ... 98
Chemical composition of the ground waters ... 99
Types of ground water ... 99
Conditions north of Kings River ... 100
Occurrence of sulphate and nonsulphate waters ... 100
Cause of the difference in composition of water ... 101
Contact zone of sulphate and nonsulphate waters ... 102
Relation between the character of the waters and the origin of the silts ... 103

Digitized by Google

Quality of the waters—Continued.
Chemical composition of the ground waters—Continued. Page.
Conditions around Tulare Lake 104
Contact zone of sulphate and non-sulphate waters 104
Total mineral content of waters 106
Thickness of the lacustrine deposits 108
Proper depth of wells near Tulare Lake 108
Conditions south of Tulare Lake 109
Composition and quality of east-side waters 110
Composition and quality of west-side waters 112
General character 112
Quality in relation to geographic position 113
Deposition of calcium sulphate 116
Composition and quality of axial waters 117
Irregularity of composition 117
Chloride content of artesian water 117
Increase of mineral content from south to north 119
General conditions 119
Deep waters 120
Occlusion of sea water 121
Shallow waters 122
Relation of depth to mineral content 122
Quality for irrigation 123
East-side waters 123
West-side waters 124
Axial waters 125
Results of using ground waters 125
Effect of cold water 127
Quality for industrial use 128
Industrial development 128
East-side waters 128
West-side waters 129
Axial waters 130
Results of using ground waters 130
Quality for domestic use 132
Depth and position of poor supplies 132
Possibility of pollution 132
Municipal supplies 133
Miscellaneous analyses 134
Analyses by the California Experiment Station 134
Analyses by the Reclamation Service 139
Forecasting quality of ground water 139
Summary 140
Pumping tests, by Herman Stabler 142
Notes on the plants 142
Tabulated results of pumping tests 165
Summary of pumping tests 168
County notes, by W. C. Mendenhall and R. B. Dole 177
San Joaquin County 177
General conditions 177
Flowing wells 178
Pumping plants 178
Quality of water 180
Well records 182

Digitized by Google

County notes—Continued. Page.
Stanislaus County ... 197
General conditions ... 197
Flowing wells ... 197
Pumping plants ... 198
Quality of ground water ... 198
Well records ... 200
Merced County ... 208
General conditions ... 208
Flowing wells ... 209
Pumping plants ... 209
Quality of water ... 210
Well records ... 212
Madera County ... 226
General conditions ... 226
Flowing wells ... 226
Pumping plants ... 227
Quality of water ... 227
Well records ... 229
Fresno County ... 234
General conditions ... 234
Flowing wells ... 236
Quality of water ... 237
Well records ... 239
Tulare County ... 252
General conditions ... 252
Flowing wells ... 252
Pumping plants ... 253
Permanence of the ground-water supply ... 253
Quality of water ... 255
Well records ... 256
Kings County ... 281
General conditions ... 281
Flowing wells ... 282
Quality of water ... 283
Well records ... 284
Kern County ... 289
General conditions ... 289
Flowing wells ... 289
Pumping plants ... 290
Quality of water ... 292
Well records ... 295

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ILLUSTRATIONS.

		Page.
PLATE I.	Map of San Joaquin Valley, Cal., showing artesian areas, ground-water levels, and pumping plants examined	In pocket.
II.	Map of San Joaquin Valley showing location and depth of wells in relation to sulphate content of ground waters	In pocket.
III.	Cross sections showing sulphate content of ground waters in San Joaquin Valley	102
IV.	Map showing prospects for quality of water near Tulare Lake	108
V.	Diagram showing mineral content of ground waters in San Joaquin Valley	120
FIGURE 1.	Index map showing location of San Joaquin Valley	16
2.	Longitudinal sections showing sulphate content of ground water in the vicinity of Tulare Lake	105
3.	Cross sections showing mineral content of ground water in the vicinity of Tulare Lake	107
4.	Cross section showing content of sulphate and total mineral matter of ground waters in the basin of Kern Lake	110

INSERTS.

		Page.
TABLE 34.	Summary of pumping plant data	168
37.	Field assays of ground waters in San Joaquin County	180
38.	Mineral analyses of ground waters in San Joaquin County	180
40.	Field assays of ground waters in Stanislaus County	198
41.	Mineral analyses of ground waters in Stanislaus County	198
43.	Field assays of ground waters in Merced County	210
44.	Mineral analyses of ground waters in Merced County	210
47.	Field assays of ground waters in Madera County	228
48.	Mineral analyses of ground waters in Madera County	228
50.	Field assays of ground waters in Fresno County	238
51.	Mineral analyses of ground waters in Fresno County	238
53.	Field assays of ground waters in Tulare County	254
54.	Mineral analyses of ground waters in Tulare County	254
56.	Field assays of ground waters in Kings County	282
57.	Mineral analyses of ground waters in Kings County	282
60.	Field assays of ground waters in Kern County	294
61.	Mineral analyses of ground waters in Kern County	294

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GROUND WATER IN SAN JOAQUIN VALLEY, CALIFORNIA.

By W. C. MENDENHALL, R. B. DOLE, and HERMAN STABLER.

INTRODUCTION.

By W. C. MENDENHALL.

DEVELOPMENT OF IRRIGATION IN THE SOUTHWEST.

The agricultural industry in the southwestern part of the United States is peculiar in that within that region consumption tends constantly to exceed production. This condition is due to the large areas of desert, which are unsuited for agriculture but support many other industries. The irrigated land in the 11 arid States, lying for the most part west of the crest of the Rocky Mountains, was 7,254,110 acres in 1899, when the Twelfth Census was taken, and 13,202,889 acres in 1909, when the Thirteenth Census was taken. Although irrigation development has not been so rapid since 1909 as during the preceding decade, it has nevertheless continued, and large tracts are added each year to the reclaimed areas through the operation of the reclamation act, the Carey Acts, the desert-land law, and the development of lands in private ownership. Meanwhile general industrial expansion continues, although less rapidly than at earlier periods, and under the influence of this expansion and the pressure of population from the East most of the Western States are making important additions to their population each year.

In the States of Nevada, Arizona, and New Mexico the mining industry becomes yearly of greater importance, and the influx of people engaged in it is increasing correspondingly. The increase in the production of petroleum in California from 395,000 barrels in 1892 to 14,000,000 barrels in 1902 and 86,450,000 barrels in 1912 represents an amazing growth in an industry and in the population necessary to support it, which in turn greatly increases the demand for food products and thus stimulates agricultural development. The growth of trade with oriental countries and the development of the mineral resources of Alaska have resulted in great accessions to the population of the Pacific coast seaports, particularly those about San Francisco Bay and Puget Sound, and in greatly increased

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demands for food products. The passage in 1914 of an Alaskan railroad bill promises to increase the northern market during the construction period at least, and the completion of the Panama Canal will open eastern and European markets to certain types of Pacific coast products, to which these markets are now closed. Southern California, as that portion of the State lying south of the Tehachapi Mountains is called, has become established as a playground for the people of the entire United States, and of the thousands of tourists who visit this area each year many become permanent residents.

Of the areas in the Southwest within which food products for its cities, its tourist centers, and its mining regions must be raised, the largest and most promising is the interior lowland known as the Great Central Valley of California. The southern segment of this lowland, San Joaquin Valley, contains about 7,500,000 acres, of which 1,728,975 acres was under irrigation in 1912(?). Southern California contains approximately a million acres of land that would be cultivable if water were applied to it; yet in this region, where the water resources are fully utilized, perhaps a quarter of a million acres are under irrigation, and the remaining area either is nonproductive or yields a relatively low-grade and uncertain crop through the application of dry-farming methods.

Furthermore, the density of population in the irrigated valleys south of the Tehachapi and the large and rapidly growing cities there means the consumption of practically all the staple food products raised. Fruits, especially the citrus varieties, are grown for export, and in some years more grain is produced than is necessary for local needs; but in general the demand in this area for food staples is in excess of the local supply and this condition will be accentuated rather than ameliorated in the future.

Imperial Valley, in extreme southeastern California, is rapidly becoming a very productive area through the utilization of Colorado River water, and many other sections might be mentioned whose acreage will increase the total area under irrigation, but all of them together are smaller than San Joaquin Valley, which, with that of the Sacramento, must become the chief agricultural district of the Southwest.

The agricultural development of this valley is controlled by the distribution of rainfall, the character of the soils, and the possibility of applying other water than that which reaches the valley as a direct result of precipitation upon its surface. Its extreme southern end, in the vicinity of Bakersfield, is strictly arid, the average rainfall there being less than 5 inches. Precipitation increases gradually toward the north, until at Red Bluff, in the northern end of Sacramento Valley, the annual rainfall averages 25.7 inches. Intermediate areas receive an amount of precipitation intermediate between these

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two extremes; but south of San Francisco Bay the available records indicate a rainfall of less than 16 inches, and over the greater part of this area, of less than 12 inches—an amount insufficient to insure crops, even of grain, and entirely inadequate for the other diverse food crops which a dense population demands.

The progressive increase in aridity from the northern toward the southern end of the valley trough prevails to an equally marked extent east of the valley, in the mountain areas from which its surface waters are drawn. The total run-off from the Sierra, according to the best available records, is about 12,000,000 acre-feet annually. Of this amount, 3,300,000 acre-feet is supplied by the streams from Kings River southward and 8,700,000 acre-feet by the streams north of Kings River. The combined drainage area of the streams from Kings River southward is 4,871 square miles; that of the streams north of Kings River is 7,714 square miles. That is, a southern portion of the Sierra, whose area is nearly seven-tenths as large as the northern portion, yields but one-third as much water in the form of stream discharge. Hence in the south end of San Joaquin Valley the acreage which is irrigable by the use of surface waters is very much less than that in the northern end of the valley, and the area available for development there is correspondingly greater than that available farther north.

The question of water supply is, of course, not the only one that confronts those who desire to see the development of San Joaquin Valley proceed rapidly, although it is properly regarded as the most pressing. The quality of the soil, particularly with reference to the presence of hardpan or of alkali, is of the utmost importance. Extensive alkali areas exist along the axis of the valley and part way up its eastern slope, especially at points where the ground waters lie close to the surface, and hardpans of at least two types underlie some of the higher and otherwise most valuable lands. These soil problems are being studied systematically by the soil experts of the Department of Agriculture [1] and the reports that are issued should be supplemented as rapidly as possible, until definite information as to soils is available for the entire valley.

The conditions already outlined—namely, the great actual and the much greater prospective importance of San Joaquin Valley as an agriculturally productive center—have led during the last decade to greatly increased interest in the possibility of adding to the acreage under irrigation, and hence to the output in food products.

Irrigation enterprises, like those based upon other industries, invariably pass through a pioneer stage, in which only the most easily

[1] Lapham, Macy H., and Helleman, W. H., Soil survey of the Hanford area, California: U. S. Dept. Ag., Bur. Soils, Field Operations 1901. The results of similar surveys are available for areas about Bakersfield, Modesto, Turlock, Madera, Fresno, Portersville, and Stockton.

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accessible resources are utilized. In this stage the land holdings are large, the methods of application of water are wasteful, and the agricultural output is low. Only later, when the population becomes much more dense and the need of greater output is clearly recognized, do methods so improve that the ratio of output to area, to resources, and to investment becomes such as to satisfy reasonable economic demands.

In southern California irrigation methods have been carried to a greater degree of refinement than in any other section of the United States. When irrigation began there, during the first third of the nineteenth century, short crude ditches were constructed by which the waters utilized were diverted from the lower courses of the streams to near-by lands upon which they were turned, and the only products were grain and pasture, by which the flocks and herds were carried through the dry season. Such methods were in vogue until the late sixties and early seventies, when American settlers entered the country and attempted to utilize lands that had been regarded as entirely worthless. These settlers brought with them capital, and constructed their ditches on higher lines and in a much better manner than were the old Spanish zanjas. They applied water much less lavishly, to larger areas, and with much better unit results, and so by continued improvements of this type all of the surface waters were finally utilized to the best advantage. But settlers continued to flock to the region, and attention was then turned to the underground waters, which were developed at first only to supplement the surface supplies. Such reservoir sites as were available were also filed upon and made use of, and eventually many enterprises were started, some of which depended on a combination of surface and underground waters, and others on underground waters alone. Still later refinements resulted in the reconstruction of many of the old ditches, the replacement of open canals by underground pipes, and the elimination thereby of waste by seepage and evaporation. In the lower lands wells were drilled which yielded flowing water, and stream waters which had previously been utilized on these lower lands were diverted to the bench lands, where products of higher value could be grown.

As a result of this intensity of development it is probable that in no area in the United States are the waters so thoroughly utilized as in the region that lies south of the Tehachapi Mountains. In their passage from the mountains, where they originate in precipitation, to the sea, where they are lost, some portions of these waters are used as many as eight times—in power plants, in irrigation from surface streams, and finally by the recovery of that portion of the surface flow which, sinking into the alluvial fans, augments the supply in the underground reservoirs.

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Much of San Joaquin Valley is still in the pioneer stage of irrigation development, depending almost exclusively on surface waters, and in a large part of the area waste is great, over-use is the rule, and, as a consequence, minimum production results from a maximum use of water. But the pioneer stage is passing. Engineers trained in more refined methods are entering the region and applying their training. Special communities, like those about Portersville and Lindsay, where citrus fruits are raised, have for a decade or more used deep ground waters, whose cost greatly exceeds that of surface waters where the latter are available in other parts of the valley. This relatively high cost is amply justified, however, in the citrus belt by the great value of the product

In other parts of the valley, as, for example, in the neighborhood of Corcoran, capitalists who had profited in other regions through the use of flowing artesian waters have undertaken to develop colonies by utilizing waters of this type, whose existence had been proved years before by the owners of large cattle ranches, who had put down wells to obtain water for stock.

In still other districts, as about Bakersfield, Stockton, and Fresno, isolated individual pumping plants have been installed within the last decade, and by their use lands whose owners had been unable to secure rights to the limited supply of surface waters have been brought within the productive zone.

INVESTIGATIONS BY THE UNITED STATES GEOLOGICAL SURVEY.

These more or less isolated experiments and their successful outcome have resulted in a widespread recognition of the fact that the productivity of San Joaquin Valley can be greatly increased by the utilization of the heretofore neglected ground-water resources. This recognition has been followed logically by a desire for specific information as to the quality, occurrence, accessibility, character, and proper use of waters of this type.

In response to this demand the Geological Survey and the Reclamation Service began a study of the ground-water resources of the valley in 1905. This work was continued as funds became available in 1906 and 1907 by the engineers and geologists of the Survey, and in 1908 a preliminary report [1] was issued. The plan at that time in mind was to supplement the preliminary statistical study of developments by more comprehensive work on the geological conditions controlling the distribution and circulation of the ground waters, by a careful field reconnaissance of the chemical characteristics of the waters, since the preliminary work had revealed the importance of

[1] Mendenhall, W. C., Preliminary report on the ground waters of San Joaquin Valley, California: U. S. Geol. Survey Water-Supply Paper 222, 1908.

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this element in the problem, and by a careful study of pumping costs under various conditions as developed by the experience of irrigators in the valley. The pressure of work in other directions has rendered it impossible to carry out this plan fully. Further field geologic studies have not been possible, but the chemical reconnaissance was completed by R. B. Dole in the fall of 1910, and his report, long ready for publication, is included as a part of this volume. Herman Stabler examined a large number of pumping plants in the valley during the same season, and the results of his studies are also included for the benefit of water users in the valley.

Certain detailed data omitted from Water-Supply Paper 222 but forming the basis of many of the conclusions reached in it are also now published. The tables of wells examined and their costs, equipment, and yields are referred to especially. As a number of years have elapsed since the completion of these tables, they do not summarize the later developments. The addition of later wells would add to the mass of data rather than alter the conclusions to be drawn, however, so that their omission is not considered to be of great significance.

In the preparation of Plates I and II the topographic and engineering map of San Joaquin Valley issued by the California State Engineering Department in 1886 has been used as a foundation. Some additions and corrections have been made as a result of later surveys, especially those made by the United States Geological Survey about Bakersfield and along the southern and western borders of the valley, but the earlier map has been used substantially in its original form for the greater part of the valley. On Plate I (in pocket) the area in which flowing wells may be obtained has been outlined with as much accuracy as the information at hand permits. Beyond the limits of the belt of flowing wells the attitude of the ground-water plane has been indicated by hydrographic contours which are based on the elevations of the surface as indicated by the topographic sketch contours of the base map. Neither set of contours is accurate in detail, but it is believed that the relations between the two—that is, the depths to ground water at various points—are correct within a reasonable margin of error, so that the map will be of practical value. It must be remembered, in using this map, that ground-water levels do not everywhere remain constant. On the deltas and in the irrigated areas there is a more or less regular annual variation in level, the plane of saturation rising during the high-water period—the period of maximum irrigation in early summer—and falling during the low-water period in the autumn and early winter. In the past there has been a marked permanent rise in the ground-water level in areas to which water has been applied by the construction of the large canals of the greater irrigation systems. This rise still con-

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tinues in some localities, to which water has been applied for a number of years, and it will be marked in regions to which canal systems may be extended in the future, although the chief changes of this character have doubtless already been brought about. In one or two limited localities there is probably also a general decline in ground-water levels. It is not possible, of course, to indicate a varying water level by a single set of hydrographic contours. Those used indicate about the position and form of the water plane in the period from 1905 to 1907.

GEOGRAPHY OF THE VALLEY.

San Joaquin Valley and Sacramento Valley together constitute the Great Central Valley of California, with an area of nearly 16,000 square miles. (See fig. 1.) This level-floored depression is more than 500 miles long and varies from 20 to 50 miles in width. East of it the Sierra rises to an elevation between 14,000 and 15,000 feet above sea level, and west of it the lower Coast Ranges separate it from the Pacific. The greatest elevation of the Sierra is near its eastern edge and all its important drainage is westward toward the Great Valley, an important fact upon which the greater part of the actual and prospective agricultural value of the valley depends. The Coast Ranges are a series of parallel ridges of moderate elevation that inclose valleys, like those of the Salinas and Santa Clara, which, when not too arid, are highly productive.

The Great Valley itself exhibits little diversity in its physical aspect. Such differences as exist between its north and south ends are climatic, or, if physical, are directly due to climatic differences. Among local physical features based upon climatic differences may be mentioned the Tulare basin at the south end of San Joaquin Valley. The basin is due to the aridity of the region and the consequent extensive development of alluvial fans. Two of these, extending from Kings River on the east and Los Gatos Creek on the west side of the valley, have coalesced in a low ridge south of which lie the Tulare Lake and Kern Lake depressions. Basins different in character and situation, but originating nevertheless in climatic conditions, are the overflow basins of the Sacramento and the lower San Joaquin valleys, of which the Yolo basin may be mentioned as a type. These basins occupy the lowest portions of the flood plains just outside the ridges that form the immediate river banks.

The central valley opens to San Francisco Bay and thence to the Pacific through Carquinez Straits and the Golden Gate, and the combined drainages of the Sacramento and San Joaquin systems discharge through these gateways. Other passes, like the Tehachapi, the Tejon, and Walker Pass near the south end of San Joaquin Valley and the Livermore Valley gateway near Carquinez Straits, extend

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across the mountain barriers that surround the central lowland, but they are not so low nor so pronounced as the central tidal gateway. In general it may be said that the Great Valley is completely inclosed except for this opening.

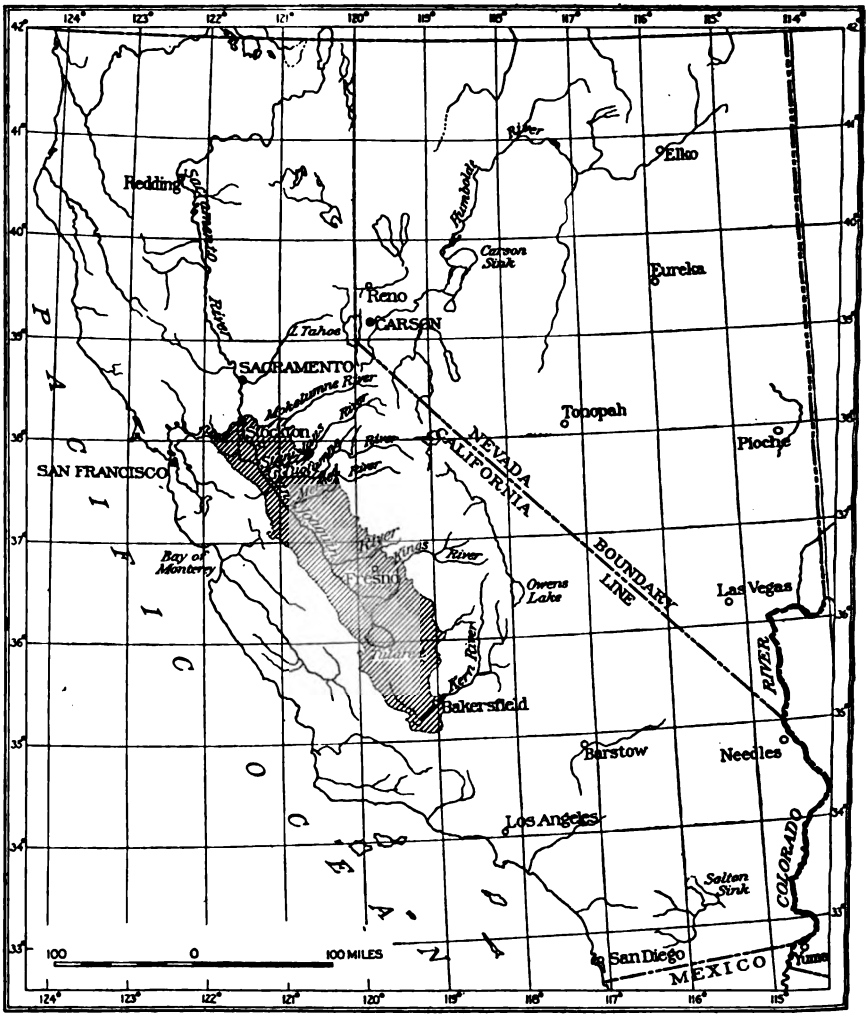

FIGURE 1.—Index map showing location of San Joaquin Valley (shaded area).

The larger lobe of the central depression, extending southward from Cosumnes River and Suisun Bay, is generally known as San Joaquin Valley, although it is not all drained directly by San Joaquin River and its tributaries. The southern, more arid third of the depression, extending from Kings River delta to Tehachapi Mountains, has no surface outlet under normal conditions, and the surplus surface waters accumulate in the Tulare Lake depression and Buena Vista

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reservoir. Originally Kern Lake received a portion of the excess from Kern River, but through the protection afforded by a restraining dike water is kept out of it except when unusual floods break the restraining dam. The original lake bottoms have now become valuable wheat lands.

The streams that drain into the valley from the Sierra carry practically all of the water that reaches it. They are in every way more important than those that enter it from the west. They have larger drainage basins, individually and collectively; they have longer courses; and they flow from higher mountains, with a much greater rainfall and a better protective covering of forest and brush; hence their discharge is many times greater and much less erratic than that of the west-side streams.

The total drainage area[1] tributary to the valley from the Sierra is 16,089 square miles; from the Tehachapi and Coast ranges 4,293 square miles; and the area of the valley floor is 11,513 square miles. The total area of the San Joaquin basin is therefore 31,895 square miles.

The average run-off of the principal east-side streams north of Kings River, with a combined drainage area of 7,714 square miles, is about 8,700,000 acre-feet, while that of Kings, Kaweah, Tule, and Kern rivers, discharging into the Tulare basin from a watershed with an area of 4,871 square miles, is about 3,300,000 acre-feet. The total discharge into the valley from 12,585 square miles of Sierra watershed is therefore about 12,000,000 acre-feet.

The preponderance of east-side streams has given the valley floor its well-marked unsymmetrical form. The valley axis, the line of lowest depression, is throughout much nearer the western than the eastern foothills. In places it lies against these hills, but elsewhere, as between Los Gatos and Cantua creeks, the west-side slopes are 15 or 18 miles wide, at least one-half as wide as those of the east side. They are also steeper than those of the east. Grades of 20 or even 40 feet to the mile are not rare, and it is unusual for the grades to be less than 6 or 8 feet per mile. On the east side 30 feet to a mile is about the maximum gradient, while 5 feet or less is perhaps the average.

These conditions are due directly to the fact that the valley floor has been built up by the alluvial material eroded by the streams from the mountains east and west of the depression and deposited in it. The larger and more active streams build flatter but more extensive alluvial fans—the type that makes up the east-side slopes; the more erratic and torrential streams of smaller volume build the steeper and less extensive fans that constitute the west-side slopes.

[1] Hall, W. H., Physical data and statistics of California, pp. 396 et seq., State Eng. Dept. California, 1886.

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GEOLOGIC OUTLINE.[1]

ROCKS OF THE BORDER OF THE VALLEY.

In simplest outline, the geology of the eastern border of San Joaquin Valley consists of the "Bedrock series" of granites and metamorphic sedimentary and igneous masses of pre-Cretaceous age, overlain at the north and south ends of the valley in an interrupted band occupying a zone of low relief between the Sierra proper and the valley proper by a series of Tertiary sediments, entirely unaltered and including beds as old as the Eocene, although the great body of the material seems to be Miocene or Pliocene in age. Between San Joaquin River and Portersville this zone of late sediments is missing, and the sands and gravels of the valley proper lie upon the flanks of the granites and the metamorphic complex. Because of this hiatus the east-side Tertiary is separated into two bodies, of which the northern extends from Fresno River nearly to the Cosumnes, and the southern, conveniently designated as the Bakersfield area, extends from Deer Creek to Cañada de las Uvas.

The northern area of Tertiary rocks, which is chiefly in the Milton-Merced regions, includes a lower, clayey series that has been called the Ione formation, a middle zone of andesitic sandstone, coarse volcanic breccias, and tuffaceous beds, and an upper gravelly series that is in places auriferous. This upper series usually occurs along the most westerly foothills and merges at many points with the gravels and soils of the valley floor.

The southern area consists of alternating beds of soft sandstone, clay, and gravel, the uppermost beds being coarse, like those of the northern area, and scarcely distinguishable in some places from the alluvium of the valley itself.

The geology of the western margin of the valley contrasts in many ways with that of the eastern border. The oldest rocks of the Mount Diablo Range—the easternmost of the coast ranges—comprise a series of altered igneous and sedimentary rocks of Jurassic (?) age known as the Franciscan formation, which extends along the axis of the range from a point southwest of Coalinga to San Francisco Bay. Overlying them on the valley side, but not continuously, is a series of sandstones, shales, and conglomerates of Cretaceous and earliest Tertiary (Eocene) age. Succeeding these in turn is a variable series, locally of great thickness and usually but not always present in some of its members, representing the middle and upper Tertiary. These rocks, like the older sediments beneath them, are sandstones, shales, and conglomerates, but usually they are less firmly indurated than the Eocene and Cretaceous rocks. They overlie the latter unconformably and contain many unconformities within themselves, with a

[1] Abstract from a manuscript by H. R. Johnson, on the geology of the borders of San Joaquin Valley.

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resulting variability in thickness and irregularity in extent of individual beds. This series contains the siliceous shales generally spoken of in literature as the Monterey, besides a great variety and abundance of sandstones and conglomerates. Toward the top of the series are beds that clearly represent fresh water or subaerial deposition, undoubtedly much like that which is now taking place in Tulare Lake and in the west-side alluvial fans. As a whole the sedimentary series dips toward the valley, although interruptions like the anticline of the Kettleman and McKittrick hills in places vary the prevailing monoclinal dips. In general the structures of the valley border are more complex at the south end than along the middle portion and at the north.

The valley as a whole is a great structural trough and appears to have been such a basin since well back in Tertiary time. Since it assumed its general troughlike form, gradual subsidence, perhaps interrupted by periods of uplift, has continued and has been accompanied by deposition alternating at least along what is now its western border with intervals of erosion. This interrupted but on the whole continuous deposition seems to have been marine during the early and middle Tertiary; but during the later Tertiary and Pleistocene, when presumably the valley had been at least roughly outlined by the growth of the Coast Ranges, fresh-water and terrestrial conditions became more and more predominant, until the relations of land and sea, of rivers and lakes, of coast line and interior, of mountain and valley, as they exist now, were gradually evolved. As these conditions developed, the ancestors of the present rivers probably brought to the salt and fresh water bodies that occupied the present site of the valley and its borders, or, in the latest phases of the development, to the land surface itself, the clays, sands, gravels, and alluvium that subsequently consolidated into the shales, sandstones, and conglomerates of the late Tertiary and Pleistocene series, just as the present rivers are supplying the alluvium that is even now accumulating over the valley floor.

The very latest of these accumulations are the sand and silt and gravel beds penetrated by the driller in his explorations for water throughout the valley. They are like the early folded sandstones, shales, and conglomerates exposed along the flanks of the valley, except that they are generally finer, and are not yet consolidated or disturbed. The greater part, perhaps all of them, accumulated as stream wash on the valley surface or in interior lakes like the present Tulare Lake, but a proportion of the older sediment that is greater as we delve farther back into the geologic past accumulated in the sea or in salt bays having free connection with the sea. It is these very latest geologic deposits, saturated below the ground-water level by

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the fresh water supplied chiefly by the Sierran streams, that constitute the reservoirs drawn upon by the wells, whether flowing or pumped, throughout the valley.

The chemical composition of the ground waters, as well as their occurrence and accessibility, is related to the geology. Where the valley alluvium is derived from the Cretaceous and Tertiary beds of the coast ranges, rich in gypsum and other readily soluble minerals, the ground waters contain large quantities of the salts. Where, on the other hand, the alluvium is derived from the granites and metamorphic rocks of the Sierra, whose potassium, sodium, and calcium compounds are in the form of difficultly soluble silicates, the ground waters under ordinary conditions contain very little of these salts.

Obviously if the sands and gravels through which the ground waters percolate were deposited under such conditions that salts were deposited with them, as in the salt water of the sea or of bays like San Francisco Bay, or in interior lakes that are saline through evaporation, as is true of Tulare Lake, then the ground waters themselves will quickly become saline, although when they leave the mountains as surface waters, before their absorption by the alluvial fans, they may be as pure natural waters as are known in the world.

ORIGIN OF THE PRESENT SURFACE OF THE VALLEY.

The lowland through the heart of California known as the Great Valley, whose origin as a depression appears, in accordance with the facts just outlined, to date well back into Tertiary time, owes its actual surface to more recent action and to more obvious agents. That surface is, in brief, a combination of the surfaces of a great number of alluvial fans, originating at the mouths of the canyons through which the tributary streams discharge from the mountains into the valley.

Each stream that enters the valley brings with it from the mountains a greater or a smaller quantity of sand, gravel, or bowlders. All or a part of this burden is deposited in the valley, and the deposit constitutes the alluvial fan of that particular stream. The apex of each fan is the mouth of the stream canyon. From this apex it broadens and flattens until it coalesces at its periphery with other fans. The stream that built it usually spreads delta-wise over it, discharging through a number of diverging channels into the trough of the valley. As a rule these spreading distributaries flow upon the surface of the fan, but some of the major streams from the San Joaquin northward are incised into the valley floor in trenches 100 feet or less in depth. This must be due to special conditions, such as recent change in volume of stream flow or in elevation of the land relative to the sea—conditions not yet understood.

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The fans of different portions of the valley indicate by their mass and form the conditions of volume and distribution of rainfall under which they originated. The west-side fans, particularly those in the middle of the valley and near its southern end, are steep and symmetrical, forms characteristic of areas of low rainfall very irregularly distributed. The east-side fans are of much greater mass and lower slope because the rivers that built them have a greater flow of somewhat less irregular character. The Kern River fan has grown westward against the McKittrick hills until it has isolated the Buena Vista basin south of it. Before dams had been built, interfering with the natural conditions here, a shallow lake occupied the present site of Buena Vista reservoir and the old bed of Kern Lake, and during seasons of unusual rainfall there was overflow northward toward Tulare Lake. The basin occupied by Tulare Lake is likewise due to the aridity of the valley and the consequent development of Kings River and Los Gatos Creek fans. South of the low, broad ridge due to the coalescing of these two fans is the Tulare basin, in which a part of the surplus water of the streams south of it accumulates. As a consequence of the flatness of this basin and the very erratic character of the supply that reaches it, the lake fluctuates widely in area during a series of years.

Northward from Tulare Lake basin the discharge of the streams is sufficiently great and sufficiently constant to prevent the formation of delta-dams like those formed by Kings River and Los Gatos Creek fans, and an open channel is maintained from the San Joaquin northward to Suisun Bay.

Along the lower course of the San Joaquin, conditions resemble those in Sacramento Valley—that is, they are the conditions usual along rivers draining humid rather than arid regions. Large areas are subject to regular annual inundation during the spring floods or are protected from this inundation only by artificial levees. The greater part of the water that inundates this area is supplied by the Sacramento system, but the greatest overflow occurs when the floods appear in the two systems at the same time.

The essential fact as to the present valley surface is that it is a direct result of stream action. It has everywhere been built up by deposition from the streams or from the fluctuating lakes that are themselves dependent upon the streams; and it is formed of materials brought by the streams from the mountainous portions of their drainage basins where they are eroding instead of depositing. Throughout the south end of the valley its surface is a combination of alluvial fan surfaces; at the north end of the valley these fans, less strikingly and typically developed because of the greater precipitation there, still predominate along the valley borders, while the center of the valley is a flood plain of the usual type.

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SOILS.

As the valley surface has been molded by stream action into its present form, so the soils of the valley represent deposition by the rivers of materials washed out of the mountains from which they drain. This soil is modified in various ways after the streams have deposited it—by disintegration of the rock particles where the streams have left them, by the mingling of the products of vegetal decay where vegetation is abundant, or by chemical processes in place, such as the formation of hardpans or the accumulation of alkalies; but the soil foundation, so to speak, reflects pretty closely the type of rock outcropping in the drainage basin of the stream on whose delta the particular soils are found.

For example, the soils of the deltas of Kern and Kings rivers are in large part of granitic derivation, because granitic rocks form the greater part of the mountain drainage basin of each of these rivers. Their coarseness and the distribution of the coarse and fine phases are to a certain extent matters of accident, due to the location of present or past channels of the streams across their deltas; but in steep alluvial fans the coarser and more bowldery soils occur nearer the mountains. In the fans of those east-side streams from the Merced northward, whose lower courses at least are cut through late Tertiary formations containing a large percentage of lavas and derived products, other types of soil result.

The west-side streams, draining mountains practically free from granites and similar rocks but with soft serpentines, shales, and sandstones, deposit fragments of those rocks in their alluvial fans, and the result is a soil type entirely different from that of the east side and south end of the valley. These shale, clay, serpentine, and sandstone fragments disintegrate much more quickly than the granitic sands that contain large proportions of such resistant minerals as quartz and feldspar, and the result is the mellow, loamy soil with its fragments of siliceous shale that makes much of the west slope of the valley and is so productive whenever water can be applied to it.

Soil of another general class occurs at a few localities along the east side of the valley. This soil is not of alluvial fan origin, brought into the valley by the streams from the surrounding mountains, but is due to decay in place of the rocks underlying the particular area where it occurs. Soils of this class are found northeast of Fresno beyond Clovis, and in some of the coves like Clark Valley north of Reedley, and perhaps in other foothill valleys in the Portersville-Lindsay district. Some of the rolling wheat lands found in a zone along the eastern border of Stanislaus and Merced counties may also be regarded as derived from the decay of rock in place rather than from inwashed alluvial fan material, but as the rock is itself a late

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Tertiary sediment differing but little from the alluvial fan material of the same area, the classification of the soils as residual rather than colluvial has no practical significance.

Another type of soil is neither more nor less than fine beach sand. This type is best developed in a zone surrounding Tulare Lake, and it represents the shore lines of that water body when it contained much more water than at present. In places this sand has been reworked by the wind—blown into inconspicuous dunes, as in the "Sand Ridge" near the Kings-Kern county line.

Finally, there are the soils of the "tule lands" and the "islands," the areas subject to overflow particularly along the lower course of the San Joaquin and its tributaries, but present, although less extensively developed, in other areas. These lands are black loams or adobes or impure peats, and when reclaimed are particularly adapted to certain classes of crops.

The Bureau of Soils of the Department of Agriculture has made detailed surveys of certain areas in San Joaquin Valley as the beginning of a general soil mapping of the entire valley. The sheets at present available cover areas about Stockton, Modesto, Turlock, Madera, Fresno, Hanford, Portersville, and Bakersfield. In the text of the reports and in the maps that accompany them, the soils are classified in great detail on a physical basis, and by a proper study of this classification the geologic origin of most of the soils may be traced.

Another task undertaken by the Bureau of Soils, of even greater immediate value, is the mapping of the alkalies.[1] This work is designed to afford suggestions as to the management and reclamation of alkali soils and prevention of the rise of the alkalies. When it has been completed for the entire valley it will be of great service in preventing sales of worthless lands to purchasers who buy in good faith with the idea of establishing homes. Many sales of this kind have been made in the valley, and any work that will tend to reduce their number is to be welcomed.

SURFACE WATERS.

The streams of San Joaquin Valley and their characteristics have been referred to incidentally in the preceding pages. These characteristics depend upon the physical geography of south-central California and the control which it exerts over climate. All of the perennial and important streams flow from the Sierra.

Precipitation within the Sierra district depends upon altitude, latitude, and longitude. Up to a certain limit precipitation increases

[1] Mackie, W. W., Reclamation of white-ash land affected with alkali at Fresno, California: U. S. Dept. Ag. Bur. Soils Bull. 42, 1907.

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with increase of altitude; beyond that limit, which at the crossing of the Central Pacific is at Cisco, 6,000 feet above sea and 1,000 feet below the summit, precipitation decreases. Rainfall decreases also southward along the summit of the Sierra as well as in the valleys; and in those parts of the range, principally its southern portion, where altitude does not increase regularly from the western toward the eastern margin, so that the effect of longitude is not obscured by that of altitude, vegetation indicates less rainfall as the desert border of the range is approached.

Under these conditions, therefore, it is evident that the greatest discharge per unit of area will come from those streams with the greater proportion of their drainage basins farthest north, in the high part of the Sierra but west of the summit.

The following table has been compiled from tables of discharge in United States Geological Survey Water-Supply Papers 298 and 299 and unpublished records for July, August, and September, 1912, and shows the yearly discharge in second-feet per square mile for certain rivers draining the western slope of the Sierra. Values are for the year ending September 30.

TABLE 1.— *Yearly discharge in second-feet per square mile of certain California rivers.*

	1905–6	1906–7	1907–8	1908–9	1909–10	1910–11	1911–12
Kern River near Bakersfield	1.08	.....	.....	1.02	0.435	0.590	0.247
Tule River at Portersville	1.73	0.805	0.423	1.50	.608	.631	.258
Kaweah River near Three Rivers	2.88	1.58	.670	2.13	.925	1.45	.548
Kings River near Sanger	3.05	2.18	.819	2.23	1.41	2.24	.764
San Joaquin River near Friant	.....	.....	.960	2.45	1.71	3.00	.878
Merced River near Merced Falls	2.58	2.70	.656	1.89	1.35	2.69	.651
Tuolumne River at Lagrange	3.24	3.45	.987	2.45	1.91	3.15	.967
Stanislaus River at Knights Ferry	3.51	4.13	.876	2.81	2.01	3.43	.863
Calaveras River at Jenny Lind	.....	.....	.....	[a] 1.80	.667	2.34	.219
Mokelumne River near Clements	2.90	3.61	1.03	2.48	1.95	3.30	.843
Cosumnes River at Michigan Bar	.....	.....	.396	1.70	1.22	2.31	.356
American River at Fairoaks	3.45	4.15	1.05	3.32	2.56	3.98	.911
Bear River at Van Trent	2.95	3.84	.988	2.78	1.35	2.70	.460
Yuba River near Smartsville	4.11	5.10	1.80	4.41	3.03	4.00	1.28
Feather River at Oroville	2.55	3.56	1.32	2.81	1.71	2.66	.791

[a] 11 months, October missing.

An examination of the above table shows that there is a general tendency toward increase in the discharge per square mile northward from the Kern to the Feather. Except Kern, Merced, Calaveras, Cosumnes, Bear, and Feather rivers the streams occupy comparable positions on the western slope of the Sierra and drain the areas of maximum precipitation for their respective latitudes. The rather regular increase northward may therefore be assigned with confidence to the effect of latitude on precipitation. The drainage basins of both the Feather and the Kern extend into the very eastern part of the Sierra beyond the zone of maximum precipitation, and the inferiority of run-off from their basins as compared with that of neighboring streams may be assigned, in part at least, to the effect of

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longitude—that is, their basins extend so far east as to be measurably affected by desert conditions. Altitude may also be a factor since the Feather and the Kern drain portions of the range which are not so high as some of the intermediate areas. The deficiencies of Merced, Calaveras, Cosumnes, and Bear rivers may be in part ascribed to altitude and in part to longitude as the major portion of their areas does not extend to the summit of the range. The discharge of the principal east-side streams and the areas drained by each are summarized in the following table, compiled from the records of the State Engineering Department of California and from those of the United States Geological Survey.

The number of years of observations from which the average discharge was determined is also given. As the length of these records varies from four to twenty-two years it is obvious that they differ in value; but on the whole they supply a concrete indication of the average amount of water discharged into the San Joaquin Valley annually by its chief streams.

TABLE 2.—*Mean annual run-off of streams from east side of San Joaquin Valley.*

Stream.	Years of record.	Length of record.	Drainage area.	Mean annual run-off.	Second-feet per square mile.
		Years.	*Square miles.*	*Acre-feet.*	
Kern and Tulare Lake basins:					
Kern River near Bakersfield	1879–1882, 1893–1906, 1908–1912.	22	2,345	695,000	0.409
Tule River near Porterville	1901–1912	11	266	137,000	.711
Kaweah River near Three Rivers.	1903–1912	9	520	506,000	1.34
Kings River near Sanger	1895–1912	17	1,740	1,940,000	1.54
San Joaquin River proper:					
San Joaquin River near Friant	1878–1882, 1896–1901, 1907–1913.	15	1,640	1,944,000	1.64
Chowchilla Creek near Buchanan.	1878–1884	6	268	111,000	.571
Mariposa Creek at foothills	1878–1884	6	122	33,100	.375
Bear Creek at foothills	1878–1884	6	166	47,200	.393
Merced River near Merced Falls.	1878–1882, 1901–1912	15	1,090	1,200,000	1.52
Tuolumne River near Lagrange.	1878–1882, 1896–1913	22	1,548	2,050,000	1.18
Stanislaus River at Knights Ferry.	1878–1882, 1896–1900, 1903–1913.	19	1,035	1,390,000	1.86
Calaveras River at Jenny Lind	1908–1912	4	395	351,000	1.23
Mokelumne River near Clements	1878–1881, 1901, 1903–1913	14	631	988,000	2.16
Dry or Jackson Creek at foothills.	1878–1884	6	283	172,000	.841
Cosumnes River at Michigan Bar.	1907–1913	6	536	400,000	1.03
Total			12,585	11,964,300	

NOTE.—Compiled from Water-Supply Paper 299. The records for 1878 to 1884 were collected by the State Engineering Department of California; many of them, however, were estimates based on run-off of adjacent streams. These estimated records have been omitted from the above compilation when records for other years were available.

The high-water period of the Sierra streams comes during the late spring and early summer months, when the snow accumulated in the winter is melting most rapidly from the mountains; the low-water flow comes during the late summer and fall months after the snows are gone and before the winter rains have begun. These characteristics are illustrated in the following table of monthly discharge of

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Kings River for 1906, as determined by the United States Geological Survey:[1]

TABLE 3.—*Monthly discharge of Kings River near Sanger, 1906.*

Month.	Discharge in second-feet.			Total in acre-feet.
	Maximum.	Minimum.	Mean.	
January	25,500	205	2,360	144,000
February	2,150	792	1,150	63,900
March	21,000	1,220	5,240	322,000
April	7,760	2,960	4,720	281,000
May	16,800	3,930	10,700	658,000
June	26,600	8,320	17,100	1,020,000
July	22,400	8,180	16,300	1,000,000
August	7,900	1,870	4,300	264,000
September	2,020	682	1,120	66,600
October	682	385	516	31,700
November	610	330	397	23,600
December	2,230	330	700	43,000

Each of the major streams discharges from the mountains upon the eastern edge of the valley in a single channel, but after reaching the valley it usually divides into a number of branches, thus spreading over its delta. This characteristic is most marked in the streams that flow into the southern end of the valley, for many of the northern tributaries are incised in the valley floor and are thus confined between definite banks. This distribution is much more pronounced during the high-water period of early summer than at other seasons of the year. A main channel of sufficient capacity to carry the low-water flow proves inadequate during the flood period, and there is then overflow into the numerous subsidiary channels.

The natural habit of all of the main streams has of course been extensively modified by irrigation. Canal systems now take from the channels practically all of the low-water flow and an important percentage of the maximum early summer flow. These systems have been described by Grunsky.[2]

The west-side streams are practically negligible as factors in the San Joaquin Valley water supply. Only a few of them are perennial, and the late summer flow of these is so slight that a few acres at most can be irrigated by their use. A trifling amount of irrigation of this type is accomplished by utilizing the waters from Los Gatos Creek, Cantua Creek, and others.

[1] U. S. Geol. Survey Water-Supply Paper 213, p. 159, 1907.

[2] Grunsky, C. E., U. S. Geol. Survey Water-Supply Papers 17, 18, and 19. These papers are no longer available for distribution, but they may be consulted in libraries.

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OCCURRENCE AND UTILIZATION OF GROUND WATER.

By W. C. MENDENHALL.

ORIGIN OF THE GROUND WATER.

The ground water of San Joaquin Valley has precisely the same origin as its surface water—namely, the rainfall and snowfall in the drainage basins tributary to the valley. It is in reality simply that portion of the surface water that sinks into the sands and gravels of the valley floor and makes the rest of its journey seaward by slow percolation through the pores between the sand grains.

One of three things happens to the water that reaches the earth's surface as precipitation: (1) It returns directly to the air by evaporation from plant, soil, or water surfaces; or (2) it flows to the sea in surface streams; or (3) it sinks into the ground and joins the body of water that saturates the soil particles below the ground-water level. It is with the latter part of the precipitation on the nearly 32,000 square miles of area included in San Joaquin Valley and the mountain watershed tributary to it that we have to deal.

In the outline of the geologic history of the valley it has been pointed out that its entire surface is made up of the surfaces of contiguous alluvial fans, and that the valley is underlain to a depth that can not be determined accurately, but that doubtless runs into thousands of feet, by porous, unconsolidated, alluvial-fan material, mingled, in some areas, with lake deposits. This material has been transported from the mountains to the valley by the agency of running water. Many times its own volume of water has passed through and over it in the course of its removal from the mountains to the valley. It was deposited by and in water and has been more or less continuously saturated ever since.

A large but quite undeterminable portion of the run-off from the mountains each year sinks and joins the ground water. Of the 3,300,000 acre-feet discharged annually into the valley south of the Kings River-San Joaquin divide, only the small portion that spills northward from Kings River itself reaches the sea over the surface, because there has been no outflow from Tulare Lake for forty years. The greater part evaporates or sinks to join the underground supply. Northward from Kings River the surface waters are greater in volume than south of it and serve effectually to keep the sands and gravels beneath them saturated.

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UNDERGROUND CIRCULATION.

Ground waters near the surface usually move slowly in the direction of the surface slope and at rates that vary with the gradient of the slope and the coarseness of the material through which they percolate. The freedom of the outlet by which they escape is also important. They may be ponded by a restricted outlet just as surface waters may. Measurements of rates of ground-water movements in San Joaquin Valley are not available, but facts stated in the following paragraph indicate pretty plainly the conditions that probably prevail:

1. The alluvial fans that make up the valley floor are generally of low slope and fine material. The fans of the Cañada de las Uvas and of San Emigdio Creek, at the south end of the valley, and of Pala Prieta and Los Gatos creeks on the west side are exceptions; but the streams that have produced them contribute so small a proportion of the ground waters that they may be disregarded. 2. The general slope of the lowest line of the valley, from the south to the north, is not only not continuous, in that it is interrupted by ridges like that north of the Tulare basin, but it averages only about 1 foot to the mile, a very low gradient for a semiarid region. 3. The wells drilled throughout the valley prove that the sediments underlying it are all fine. 4. The surface outlet of the San Joaquin and Sacramento drainage is by way of Suisun Bay and the straits of Carquinez to San Francisco Bay; but the straits are restricted, and it is not probable that bedrock lies far beneath the surface in their vicinity. In short, there is no adequate outlet for the ground waters of the Great Valley, which is canoe-shaped, with only a notch in the rim at the straits through which the surface waters spill. All these conditions favor slow movement of the ground waters about the borders and at the ends of the valley, with their practical stagnation along the lower San Joaquin because there is no adequate outlet for them there. To be sure, capillarity and evaporation afford some slight escape for the ground waters as they approach the surface in their slow movement along the valley axis. The great alkali areas of the west slope and of the valley trough indicate escape of ground waters, because it is by this escape that the alkalies are concentrated at the surface; but the outlet provided in this way is of slight consequence when compared with the total body of ground waters.

The belief that there is little movement in the subsurface waters of the lower San Joaquin is strengthened by a consideration of their chemical characteristics. Some of the ground waters of the upper deltas of the east side are among the purest waters of this type known, while those from the shallow flowing wells of the bottom of Tulare Lake and from the deeper wells of the north end of the valley are so

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heavily charged with mineral matter as not to be potable or suitable for irrigation purposes. Ground waters dissolve the soluble minerals from the rock fragments—the clay, sand, or gravel particles with which they are in contact. The amount thus dissolved depends upon the chemical combinations in which the minerals exist, some being much more soluble than others, and upon the length of time during which the waters are in contact with them. In general, the alkalies in the sands and gravels of the east side are in the most resistant form, the silicates of the granitic débris from the Sierra; the alkalies of the sands and gravels of the west side are in less resistant form, the sulphates and carbonates of the Cretaceous and Tertiary shales and sandstones; hence the ground waters of the high parts of the east slopes of the valley, which move with comparative rapidity, are much purer than the waters from similar situations on the west side. Furthermore, the volume of water poured out upon the east-side fans is many times greater than that discharged upon the west side, so that the alkalies dissolved are greatly diluted. But down in the trough of the valley, especially near its north end, the ground waters contain a much larger percentage of salts, even than those of the west side. If there were rapid circulation of ground waters here, this condition should not exist, for the dissolved salts should be gradually carried out. The fact that the waters are highly mineralized is regarded then as additional evidence of sluggish circulation, or perhaps practical stagnation.

QUANTITY OF GROUND WATER.

Little need be said of the quantity of ground water in the valley, for two reasons: The first is that although it is clear that the quantity is enormous, it is not possible to estimate it with any exactness; the second is that the actual quantity is not of so much importance in its use as its accessibility and the rapidity with which it is restored when withdrawn.

The area of the valley is about 11,500 square miles. The depth of the sands and gravels which are saturated with the ground waters is probably not less than a mile at the maximum, and may be much more. The average depth is equally unknown, but wells 1,000 or 2,000 feet deep, or even more, that are scattered throughout the valley, do not reach the bottom of the unconsolidated sands and gravels; so it may safely be assumed to be one-quarter of a mile and more. At this depth, nearly 3,000 cubic miles of sands, gravels, and clays are saturated with ground water, and if the porosity is 20 per cent the conclusion is reached that 600 cubic miles of water underlies the valley—certainly both a sufficiently conservative and a sufficiently startling estimate. But this includes waters of all qualities, some not usable, and some lying at great depths and not accessible.

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ACCESSIBILITY AND AVAILABILITY OF GROUND WATER.

One of the most important elements in the cost of ground water, of course, is its accessibility, by which is generally meant the depth at which it stands beneath the surface; but the depth of boring necessary to develop it and, if pumped, the amount that it is drawn down when the pumps are in operation are also important elements.

The cheapest waters in general are those that flow out at the surface, even though deep wells may be necessary to develop them and the initial cost may therefore be great. But these waters may not always be most available, because they are to be had only in the lower parts of the valley, where, because of climatic conditions and alkalinity of soil, many of the lands are less valuable than those farther up the slopes. Generally speaking, about the borders of the valley the ground waters lie at the shallowest depths in the deltas and at the greatest depths in the interareas. The flood channels and the irrigation ditches are the lines along which recharge of the ground waters is effected; hence in their vicinity the ground-water level lies near the surface and the pumping lift is at a minimum.

Beneath the higher parts of the west-side slopes, unfortunately, where water is most needed, it is not accessible. The conditions here illustrate well the dependence of the ground water upon local surface supply. Surface run-off is most limited in this area and the ground water lies at too great depth for profitable utilization.

DEVELOPMENT OF GROUND WATER.

The development of ground water in the valley is as yet in its infancy. It does not compare in intensity with that in southern California, where, with an irrigated district of perhaps a quarter of a million acres, there are nearly 3,000 flowing wells, costing about $675,000 and yielding nearly 200 cubic feet of water per second, and at least 1,500 pumping plants in which $2,500,000 or more is invested, by which an average of nearly 300 cubic feet per second of water is produced. Other minor wells increase the investment, but add little to the product. The total estimated investment in the development of ground water, exclusive of the distribution systems, is about $5,000,000 in this restricted district and the water produced is approximately 500 cubic feet per second. For comparison with this development south of the Tehachapi, the following estimates have been prepared from the records obtained by the United States Geological Survey in 1905–1907 to indicate the relatively meager development in San Joaquin Valley at that time.

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TABLE 4.—*Ground-water development in San Joaquin Valley in 1906.*

County.	Number of artesian wells.	Estimated cost.	Estimated yield.	Number of pumping plants.	Estimated cost, well and plant.	Estimated capacity.	Estimated output (one-sixth capacity).	Total cost.	Total yield.
			Sec.-ft.			*Sec.-ft.*			*Sec.-ft.*
Kern	112	$161,400	73.46	104	$138,632	255.84	42.64	$300,032	116.1
Tulare	124	189,908	23.31	191	244,098	162.72	[a] 54.24	434,066	77.55
Kings	77	112,959	19.3	3	1,530	1.34	.24	114,489	19.54
Fresno	40	40,000	7.5	28	.....	30	5	.....	12.50
Madera	31	13,237	7.81	17	44,931	40.8	6.8	58,168	14.61
Merced	133	48,013	7.95	43	46,700	40.93	6.82	94,713	14.77
Stanislaus	5	3,830	1	9	.....	8.35	1.39	.....	2.39
San Joaquin	.....	.....	.....	202	123,836	250	41.67	.....	41.67
	522	569,407	140.33	597	599,727	759.98	158.80	1,001,468	299.13

[a] One-third capacity.

The data on which these estimates were based were neither so complete nor so satisfactory as those used in southern California, and therefore the conclusions must be regarded as suggestive rather than as accurate in detail. As an example of one of the weak points in the estimates, attention may be called to the column in which the output of the pumping plants is recorded. Generally these plants are used in the irrigation of alfalfa or of garden products. Some of them are independent sources of water; others are auxiliary to gravity waters and are used only when the latter are not available; some are in the southern part of the valley, where the rainfall is less than 5 inches; others are in the northern part of the valley, where the rainfall is more than twice as heavy, and where on this account less water need be applied artificially. Of course the pumps are not in constant operation anywhere, but the percentage of the year that they are run varies with local conditions. No exact estimate of this percentage can be made, but it has been assumed in the estimates that the pumps are operated the equivalent of two months continuously, hence, that their output for the year is one-sixth of what it would be were they in constant operation. This estimate is more likely to be too high than too low. In one county, Tulare, which includes the Portersville, Exeter, and Lindsay citrus districts, a larger factor is used. Most of the pumps in this county are used for citrus irrigation, and it is assumed here that their output is one-third of what it would be were they in continuous operation. This estimate should not be excessive.

Accepting the estimates, then, as they are, we find that in San Joaquin Valley there were in 1905–6 between 500 and 600 flowing wells and a somewhat greater number of pumping plants, representing an investment between $1,000,000 and $1,500,000 and yielding in the neighborhood of 300 cubic feet per second. The number of wells then was about one-fourth that of southern California, the investment one-third, and the product about one-half, although the total irrigable

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area of San Joaquin Valley is nearly 10 times that of the southern field and the ground waters available are probably in similar ratio. This comparison, even though the figures upon which it is based are not complete, gives a graphic idea of the development that may yet be accomplished in central California by the full use of the ground-water resources.

A later review of ground-water development and conditions has been prepared by S. T. Harding and Ralph D. Robertson.[1] Their conclusions, based largely on the data herein presented but supplemented by some later statistical information, may be quoted:

> It is estimated in this report [Water-Supply Paper 222] that the ultimate amount of ground water developed may be 10 times that then developed in southern California, or 5,000 cubic feet per second. At that time [1905–6] about 300 cubic feet per second was being developed in the San Joaquin Valley. This has been more than doubled since. If 5,000 cubic feet per second is obtained for six months of the year, it will equal a total of 1,810,000 acre-feet, or approximately 15 per cent of the total mean annual discharge of the streams at the edge of the valley. Considering the generally open structure of the subsoils, the seepage of this amount or more can be considered as reasonable. Increase in gravity irrigation should increase the quantity reaching ground supplies. Ground water in sufficient quantity for irrigation can be obtained in all parts of the valley proper, except in the west-side areas. In the lower valley floor artesian flow can be secured, although this is not extensively used for irrigation. While the quantities available decrease and the lifts required increase from the valley trough to the east-side foothills, the value of the products which can be grown increases, so that the highest development may be found in the regions of smallest ground-water supply. As pumping for irrigation requires both an initial cost and an operation expense that are plainly evident to irrigators, the pumped water is generally used more economically than that from gravity canals. As a large portion of the water at present pumped is used to supplement the water received from canals, it is not reasonable to expect the area irrigated from ground water will be entirely additional to that irrigated from canals. While any estimate of the total possibilities of the ground supplies must be liable to much uncertainty, the area eventually irrigated wholly by this means will certainly be several times that at present supplied and may reach a total of 600,000 acres. While use of ground water will be rather general throughout the lower valley floor and east-side plains, the largest use will be where gravity supplies are the least accessible, as in San Joaquin County, or where supplemental pump supplies are the most profitable, as in the Fresno district.

VALUE OF THE WATERS FOR IRRIGATION.

Although the ground waters of the valley have been known and used in minor ways practically ever since its settlement, it is nevertheless true that the movement for their extensive utilization as sources of irrigation supply is a late phase of development, for many of the earlier attempts to make use of them resulted in failure.

Among the causes that have contributed to past failures may be mentioned: Application of the developed waters to poor lands;

[1] Harding, S. T., and Robertson, R. D., Irrigation resources of central California: California Conservation Comm. Rept. for 1912, pp. 172–240.

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wasteful methods of application; dependence on the continuance of artesian flow; lack of adjustment to the greater cost of pumped waters as compared with that of the gravity waters upon which reliance has heretofore been placed; lack of intensive farming methods and of proper adaptation of crops to soil and locality; too large farm units; and, in a few cases, inadequate transportation facilities.

The most potent of all these causes has been the prevalence of the easy-going methods of the pioneer—the careless, wasteful habits that are a direct inheritance from the grazing and grain-raising period which has not yet passed from the valley. Land and such waters as are utilized have cost little heretofore in San Joaquin Valley, and things that cost little are lightly valued, no matter what their intrinsic worth. This spirit is fostered by the immense holdings of some of the larger companies. Few of these companies practice intensive cultivation, though their lands are among the best in the valley. Usually hay and grain are raised to feed through the dry season the stock that is in pasture during the grazing period. But although not as a rule intensely cultivated and by no means producing the maximum of food products or supporting the largest possible population, most of the large holdings are more carefully and successfully managed than the quarter section of the small farmer.

Despite all obstacles and discouragements, however, the use of ground waters is gradually extending. Special high-priced products like the citrus fruits of the Portersville-Lindsay district justify heavy expenditures for production, and ground water has long been successfully used in this section. The success of pumping water to great heights to irrigate the specially early citrus fruits of this region is fully demonstrated, the acreage devoted to these products is constantly extending, and the yield is increasing rapidly as groves planted recently approach maturity.

Irrigation by means of pumped ground water is also proving successful under the entirely different conditions that exist about Lathrop, Lodi, and Stockton, in San Joaquin County. Several hundred small pumping plants are in operation in this county, the greater number of which have been installed within a few years. By their use alfalfa, vineyards, and varied crops of fruits and vegetables are successfully grown. Windmills also are extensively used, often with auxiliary gas engines attached to the same well. The area in which this type of irrigation is practiced is closely settled, houses are neat, prosperous looking, and well cared for, the villages and cities which supply the country trade and market the products are flourishing, and altogether there is every evidence of successful endeavor and abundant prosperity.

Still other communities whose existence depends upon the utilization of ground waters are the recently established colonies in Kings,

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Tulare, and Kern counties, of which the Corcoran settlement is a type. This particular locality is within the artesian basin, and a group of deep wells yield flowing waters which are utilized for all purposes. As a result, successful dairy farms have been established, sugar beets are raised, and a factory has been built for the manufacture of sugar from them.

It is thus evident that there is a gradual awakening to the value of the ground waters and their usability, although in many localities the advocate of the use of these waters is still met by the statement that they can not be developed and applied at a profit under agricultural conditions as they now exist. It is true that the pumped waters are more expensive than the ditch waters, whose cost as a rule is very low. The average cost of current for pumping the water used by the Kern County Land Co. near Bakersfield, with an average lift of 30 feet, is $1.29 per second-foot for 24 hours on the basis of a charge of 15 cents per horsepower per hour for electric current, whereas the charge for surface water in the same locality is 75 cents per second-foot for 24 hours—that is, the current for pumping the ground water costs more than the surface water. When it is remembered, however, that almost universally in San Joaquin Valley water is used in great excess, to the immediate and ultimate injury not only of the lands to which it is applied but of adjacent lands; that on many of the delta lands there is as yet but little intensive cultivation, and that therefore the margin of profit is low; that there is an important proportion of large holdings and absentee ownership dependent upon inefficient hired labor; and above all that, in the midst of the communities in which it is asserted that pumped waters can not be profitably used in agriculture individuals may generally be found who are using them with striking success; when all of these things are taken into consideration, it may be asserted with confidence that the greatest increase in the agricultural development in this valley in the future will be brought about by a utilization of the ground-water supplies, whose development has only begun and whose value is as yet but faintly realized.

It will probably be true in the future, as it has been in the past, that side by side with successful attempts at the utilization of ground waters will be unsuccessful attempts, and that the general movement for full realization upon this asset will be checked here and there by conspicuous failures widely advertised. This is a condition that always arises in any general advance. Each failure should teach its individual lesson as to a particular way *not* to undertake development or to apply water, and should not be interpreted as an argument against the usefulness of the resource under proper conditions, for the fundamental facts remain that ground waters exist beneath the floor of San Joaquin Valley in immense volume and that over wide areas they are of high quality and very accessible.

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They are certain, therefore, to be widely used in the future, and by their use hundreds of thousands of acres now arid and unproductive will be brought to yield handsomely.

The development of the ground waters under the conditions that exist at present, when the chief argument against them is their cost as compared with that of the surface waters which have set the standard, should follow two or three lines.

In the first place, pumping plants in the higher parts of the delta lands should be used as adjuncts to insufficient gravity supplies. The supply of the gravity waters during the flood months of May, June, and July is from 2 or 3 to 15 or 20 times that available during the months of August, September, and October, when many crops are maturing. As a consequence many owners of late rights to gravity waters secure a portion of the flow during the early high-water period, but are left without it during the low-water period, when there is only sufficient to satisfy the earliest rights. Such owners often have enough gravity water for one or two early irrigations, but not more. Under present conditions, therefore, the maturing of late crops is a precarious matter with them, and they are confined practically to those products which will yield returns when irrigated only in the spring or early summer. This is a serious handicap, as it greatly limits the range of their agricultural activity and often condemns their land to idleness during half of the year. By the installation of pumping plants, to be operated only when gravity waters are not available, this handicap is removed, and yet the cost of irrigation is much less than where no surface waters are available and pumps must be operated continuously.

In the second place, in districts that have a market for garden products or for those special farm products whose value and yield justify some expense in their production, as sweet potatoes, celery, asparagus, or onions, the small land owner can well afford to install an individual pumping plant independent of surface supplies. The same method will be successful with crops that require only one or two irrigations a year, as, for example, some of the fancy varieties of grapes that are now raised so profitably in the northern part of the valley.

Another line to be followed in development is the utilization of flowing artesian waters. Along the axis of the valley is a zone with an area of about 4,300 square miles within which flowing waters are available. Over perhaps two-thirds of this area the flowing waters are sufficiently pure to be suitable for use in irrigation.

None of these lines along which it is suggested that ground waters may be used are experiments. Each has been followed successfully in some of the communities in the valley, although in other sections quite as favorably situated the investigator will be told that pumped

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or flowing waters can not be used profitably. Communities, like individuals, fall into ruts, acquire bad habits, and lose the power of initiative. In this condition they may overlook or fail to utilize some of their most valuable assets.

In the course of this investigation nearly 4,000 wells in the valley have been examined and data collected as to depth, yield, cost, etc. Among them are many flowing wells. For most of the wells the data are incomplete, but from the records available the following averages have been determined:

TABLE 5.—*Average size, depth, yield, cost, etc., of flowing wells.*

County.	Number averaged.	Average diameter (inches).	Depth (feet).	Yield (miner's inches).[a]	Average cost.	Annual interest on cost at 8 per cent.	Interest charge per miner's inch per year.
Kern	10	10	621	53.3	$1,545	$123.60	$2.30
Kings	7	9	1,037	30	2,555	204.40	6.81
Tulare	32	8	745	26	1,711	136.88	5.26
Fresno	7	8	936	20	1,540	123.20	6.16
Merced	16	7	350	5½	470	37.60	6.84

[a] A California miner's inch equals 0.02 second-foot.

These averages are based upon the actual experience of owners of wells already drilled and flowing. They therefore have a definite value as a basis for estimating costs of artesian waters to be obtained as a result of future developments. They may be compared with the charge made on the Kern delta for gravity water, namely, 75 cents per second-foot for 24 hours, equivalent to $5.47 per miner's inch per annum.

In comment upon the table it is to be said that the Kern County average is too low, because it happens that among the wells for which sufficiently complete data exist for computing these averages there were one or two of exceptionally great yield that have unduly raised the average yield and reduced the cost, thereby giving a figure lower than that which will probably be realized in future development.

It must be remembered further that the figures are based on the assumption that the entire year's flow will be utilized. This assumption can be realized only by the construction of reservoirs in which the water will be stored during the nonirrigating season for use when wanted. Such construction will add to the cost and will reduce the supply in three ways: (1) By a reduction of flow because of the increased height of delivery necessary to discharge into a reservoir; (2) through loss by evaporation from the surface of the reservoir; (3) through loss by seepage from the reservoir.

The uncertainty as to the amount that will be delivered by any artesian well is another disturbing factor in making exact calcula-

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tions. The area within which flowing waters are procurable has been outlined with approximate accuracy, but the yield of any well can be determined only after the well has been sunk and the necessary capital invested in it. Some of the wells used in computations have delivered much more than the average supply and so have yielded exceptionally cheap waters; others have delivered less than the average, and their waters are correspondingly expensive.

Another condition that must be realized is this: When the number of wells drawing from the artesian supply is greatly increased in any particular neighborhood, the wells interfere and the yield of each is lessened. When the maximum acreage is dependent on artesian flow under these conditions, the installation of pumping machinery may become necessary in order to insure the continuance of an adequate water supply.

As against these disadvantages, which have been rather fully outlined, as is essential in any frank and therefore useful discussion, are to be placed regularity and relative constancy of the supply and its availability at all times, as compared with the fluctuations of surface waters unavailable except during the flood season to any but the owners of the oldest rights. An added advantage where the landowner owns his well is his complete control over his water supply. He may irrigate when and how he will, and thus most economically, and is not dependent upon the adjustment of supply among a number of users from a common source.

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QUALITY OF THE WATERS.

By R. B. Dole.

IMPORTANCE OF QUALITY.

The wide range in the mineral content and consequently in the usefulness of the ground waters of San Joaquin Valley makes it necessary to know their composition before undertaking water projects involving any considerable expenditure. Most of the surface run-off may be used indefinitely in irrigation without deleterious effect, and ground water nearly as good can be obtained in many parts of the region, while certain aquifers yield supplies abundant in quantity but so highly mineralized that they are poisonous to vegetation. In the estimation of the railroad locator the amount of dissolved solids throughout the entire area is such as to make the quality of the water supplies equal in importance to quantity. Softening plants are necessary on the west side, and railroads are obliged to haul water to several stations, where the available supplies are unfit for steaming. In further extension of railroads through some townships the difficulty of procuring supplies that can be rendered suitable for locomotives will doubtless make quality of water the determining factor in the location of tanks, stations, and roundhouses. The wineries, breweries, ice factories, and laundries also must have water of proper quality, and the establishment of paper mills, strawboard mills, starch factories, sugar works, and other water-consuming mills of industries closely related to modern farming will make the quality of this important raw material a still more pressing problem. At present the needs of irrigation turn attention to all possible sources, because the demands of intensive farming have so far exceeded the available surface supply that underground waters are largely utilized and are depended on exclusively in some districts. This rapidly increasing draft on the ground reservoirs will ultimately bring about complete utilization of all supplies that can be safely applied under careful supervision and improved methods of irrigation.

Study of the chemical characteristics of water in this region is particularly interesting because of the great variety of conditions that affect the mineral content. The east side of the valley, filled with alluvium derived from hard, difficultly soluble rocks and furnished with water from the granitics of the Sierra, yields supplies entirely distinct in composition from those of the alluvium of the west side, which has been washed down from the gypsiferous sedimentaries of

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the Coast Range. The amount of rainfall decreases southward from that of the semihumid country around Suisun Bay to that of the arid region in lower Kern County, the average annual precipitation at Lodi being about 18 inches, at Fresno 9 inches, and at Bakersfield only 5 inches. Both ground and surface waters are affected in composition not only by this progressive decrease of precipitation from north to south but also by the equally apparent difference in the amount of water received by the two sides of the valley. As the total precipitation on the west slopes of the Sierra is much greater than that on the east side of the Coast Range the streams of the east side of the valley exceed those of the west side in size and number, and a proportionate difference in quantity of ground water is reflected in its composition. A relation between topography and quality is traceable in the low ridges of the deltas, which favor the deposition of salts by confining strong solutions in small basins, thus establishing tracts where wells yield highly mineralized water. Changes in mineral content due to irrigation are shown by dilution of normal water in some sections and accumulation of alkali in others. The influence of these conditions of climate, geology, and economic development on the composition of the mineral matter makes study of the water instructive and pleasurable, while the agricultural and industrial interests that are involved render the results of great immediate value.

SOURCES OF DATA.

Most of the conclusions regarding the quality of the ground waters are based on the results of 400 partial assays made by the writer during the fall of 1910. Information regarding the effect of the waters in irrigation, steaming, and other uses was obtained by visiting about 500 wells. The general plan of the field study was to travel back and forth across the axis of the valley and to test as many samples as possible from wells of different depths near what was clearly recognized as the critical area—that along the axial line. Though this scheme was generally successful wells sufficiently varied in depth could not be found in some localities, and the onset of the rainy season finally prevented the completion of studies in Kern County. Fifty samples of water were analyzed by Mr. F. M. Eaton, of San Francisco, in order to supply more complete information regarding certain sources and to afford a check on the field assays. In addition a few waters were analyzed by Mr. Walton Van Winkle. The locations of the waters that have been tested are shown in Plate II (in pocket).

The quality of the surface waters was so thoroughly investigated by Van Winkle and Eaton[1] that it was not necessary to make any further tests, and statements herein about the mineral content of the surface waters are based entirely on their work.

[1] Van Winkle, Walton, and Eaton, F. M., The quality of the surface waters of California: U. S. Geol. Survey Water-Supply Paper 237, 1910.

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Valuable knowledge regarding the composition of the ground waters is afforded by miscellaneous analyses performed at the agricultural experiment station of the University of California; as these analyses are in such form that it is not practicable to incorporate them in the general part of this report they are appended in a separate table. Special acknowledgment is due to Mr. Howard Stillman, engineer of tests, Southern Pacific Co., and to Mr. W. A. Powers, chief chemist of the Santa Fe Railway Co., for placing at the disposal of the Survey analyses of the water supplies along the rights of way of these railroads.

CONDITIONS OF COLLECTION OF SAMPLES.

Though the mineral content of water from shallow wells in humid regions is materially lessened by the dilution following heavy rainfall, an opposite effect is produced by similar rainfall in areas of low precipitation because the water in a humid region percolates downward through layers that have been deprived of their easily soluble matter by long-continued leaching, whereas the sinking water on arid land dissolves the alkali in the upper soil and carries more or less of it into the wells, which ordinarily draw their supplies from below the belt of concentrated alkali. As the dry soils in arid regions are either highly absorbent or impervious occasional light rains do not affect shallow wells, but long-continued transmission of such nearly pure water, such as occurs near canals and in dry watercourses, removes the soluble salts from the ground so that shallow wells in the immediate vicinity yield better water than those farther away. Deep wells are certainly affected by long-continued periods of drought or rainfall, but how soon, to what extent, and in what manner are problems for which there is only theoretical solution. Consequently, as the concentration of shallow-well waters in San Joaquin Valley might be changed by heavy rainfall the conditions of precipitation during the year in which the samples were taken may be noted.

TABLE 6.—*Inches of precipitation in San Joaquin Valley during 1910.*[1]

Station.	County.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Year.
Lodi	San Joaquin	2.35	1.76	2.53	0.15	0.02	Tr.	0.00	0.00	0.46	0.32	0.21	1.27	9.07
Farmington	do	3.24	2.26	3.70	.17	.05	0.00	.00	.00	.50	.38	.38	.94	11.62
Tracy	do	1.90	1.20	.....	.00	.00	.00	.00	.....	.....	.10	.05	.42	.....
Oakdale	Stanislaus	2.95	.83	3.28	.34	.06	.00	.00	.00	.29	.16	.39	.67	8.97
Denair	do	1.56	.55	3.00	.72	.01	.00	.00	.00	.20	.04	.04	.02	6.14
Newman	do	1.99	.28	2.60	.18	.00	.00	.00	.00	.52	.12	.19	.51	6.39
Le Grand	Merced	2.10	.48	1.88	.83	.00	.00	.20	.00	.30	.83	.73	.28	7.63
Los Banos	do	3.22	.30	2.03	.00	.....	.00	.00	.00	.25	.28	.26	.47	6.81
Storey	Madera	.67	.50	1.40	.49	.00	.00	.00	.00	.75	.80	.....	.26	.....
Fresno	Fresno	1.22	.21	1.28	.27	Tr.	Tr.	Tr.	.00	1.00	.45	.24	.21	4.88
Selma	do	2.00	.14	1.09	.35	.00	.00	.00	.00	1.50	.55	.33	.47	6.43
Hanford	Kings	2.40	.00	1.66	.....	.....	.00	.00	.00	.....	.31	.....	.....	.....
Portersville	Tulare	2.37	.22	1.96	.34	.00	.00	.04	.00	.14	.64	.36	1.03	7.10
Angiola	do	.66	.00	1.45	.....	.00	.00	.00	.00	.88	.57	.30	.60	.....
Wasco	Kern	1.79	.00	.68	.16	.00	.00	.00	.00	.85	.25	.19	.70	4.62
Bakersfield	do	1.15	.22	1.20	.00	.00	.00	.00	.00	.00	.83	1.37	.54	5.31

[1] Compiled from the Monthly Weather Review, U. S. Dept. Agr., Weather Bureau, 1910.

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The total precipitation in the valley for the year was considerably less than the average during the preceding 10 years, the northern stations showing greater deficiency than the southern ones. According to Table 6, in which the records of 16 selected stations are arranged in geographical order from north to south, one-half to three-fourths of the rain fell during the first four months of the year. There was practically no rain at all between April and the middle of September, and all the streams throughout the valley were markedly low during that period. Unusually early and heavy rainfall took place September 14, 15, and 16, but as the ground had been so long without rain the effect of the influx on the quality of the ground water was probably inappreciable. Some slight showers occurred during October, but they were barely sufficient to dampen the surface of the ground and are negligible. More rain fell during November, but the field work had been carried by that time below Fresno into the semiarid region where the precipitation was proportionately light. The stream discharges were little affected by the November rains. The rainfall during December was far below normal, though the showers throughout Kern County were heavy enough to make the ground muddy. Field work was discontinued December 6, but a few samples, especially from deep wells in Fresno County, were collected the middle of December. Evidently, therefore, the samples were collected during or after the dry season before the ground could be affected by winter rains, and in a year of exceptionally low precipitation; consequently the mineral content of the waters may be considered to be normal. The greatest deviations from what may be looked upon as normal were found in waters from shallow wells near stream beds or flooded irrigation ditches, but such conditions could easily be recognized, and they have been noted in the detailed descriptions.

METHODS OF EXAMINATION.

FIELD ASSAY.

As the limited time and funds for the work prohibited complete analysis of all the samples and as such analyses of only a few waters could not be typical of waters over large areas, it was decided to test a great many waters as nearly correct in the field as such work can be done and to amplify and corroborate these data by a few laboratory analyses. The methods of assay described by Leighton [1] were employed in the field work, determinations being made of total hardness, and the carbonate, bicarbonate, sulphate, and chloride radicles. Color also was estimated in a few waters.

[1] Leighton, M. O., Field assay of water: U. S. Geol. Survey Water-Supply Paper 151, 1905.

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CARBONATE AND BICARBONATE.

For the carbonate test 10 drops of a 1 per cent solution of phenolphthalein was added to 100 cubic centimeters of the water in a glazed white porcelain mortar, and the solution was then titrated with tablets of sodium acid sulphate, each of which was equivalent to about 1 milligram of carbonate (CO_3). Few waters contained normal carbonate; consequently a qualitative test with the indicator was sufficient to show their absence. Quarters of tablets, made by slicing with a knife, were used for more accurate estimation. Some tablets were then dissolved in a fresh portion of water to which 2 drops of a one-tenth per cent solution of methyl orange had been added, and the mixture was titrated with the water to an alkaline reaction. The amount of bicarbonate was computed by the formula

$$x = \frac{1000nA}{W} - 2B$$

in which W = amount of water in cubic centimeters, A = the value of 1 tablet in milligrams of HCO_3, n = the number of tablets, x = parts per million of HCO_3, and B = parts per million of CO_3 as determined by the previous test.

CHLORINE.

A measured amount of the water, to which 5 drops of a 5 per cent solution of potassium chromate had been added, was titrated in the mortar with tablets containing silver nitrate, which were crushed and triturated by a pestle. The content of chlorine in parts per million can be calculated from the number and the standard of the tablets and the amount of water. Two strengths of tablets were used, one having an equivalent of about 1 milligram and the other about 10 milligrams of chlorine. Chlorines less than 300 parts were estimated in 50 cubic centimeters of water with the weaker tablets cut in quarters. Titration of greater amounts was commenced with the stronger tablets, and waters containing more than 2,000 parts per million of chlorine were diluted with distilled water before titration.

SULPHATE.

For estimation of sulphate 100 cubic centimeters of the water was slightly acidulated with hydrochloric acid (1—1), about 1 gram of moderately coarse crystals of barium chloride was added, and the cold mixture was vigorously shaken until the crystals were completely dissolved. This treatment precipitates barium sulphate in a finely divided state, and imparts to the liquid a turbidity the degree of which is proportional to the amount of sulphate and can be determined in the turbidimeter. This instrument consists essentially

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of a glass tube inclosed in an open-bottomed brass tube suspended by a large-headed tripod over a standard candle, whose flame is kept automatically 3 inches from the bottom of the glass tube. The latter is graduated in millimeters from bottom to top in one scale and in cubic centimeters in another, so that it serves both as a depth measure for turbidity readings and as a graduate for general use. The liquid containing the precipitate of barium sulphate, after being thoroughly agitated, was poured into the graduated tube until the image of the flame disappeared. The depth in millimeters of the liquid in the tube was then read across the bottom of the meniscus, and the corresponding amount of the sulphate radicle (SO_4) was found by reference to the rating table of the turbidimeter. The readings were made in a darkened place and usually after dark. It was customary to average the results obtained on three or more precipitations. Direct readings were made for amounts between 30 and 400 parts per million, and less than 30 parts were estimated as trace, 5, 10, or 20 parts by the turbid appearance of the mixture. Appropriate dilutions were made for amounts exceeding 400 parts.

TOTAL HARDNESS.

Total hardness is determined in the field tests by adding to a measured amount of the water tablets containing a known amount of sodium oleate until the liquid after vigorous shaking forms a foam that does not break in five minutes while the bottle rests in a horizontal position. This substitution of tablets for the soap solution commonly employed in the laboratory is entirely satisfactory from the standpoint of accuracy, and it also obviates carrying a bulky bottle of soap, but so many tests had to be made and the time consumed in grinding the oleate tablets is so considerable that it was more economical to use a short burette and an alcoholic solution of Castile soap each cubic centimeter of which was equivalent to about 1 milligram of $CaCO_3$. Fifty cubic centimeters of water was titrated, allowance being made in computing the hardness for the soap consumed by 50 cubic centimeters of distilled water. So much dependence is placed on the estimate of total hardness in interpreting the results of the field assays that dilutions with distilled water were frequently made in order that interference by the insoluble soaps of the alkaline earths might be avoided.

PROBABLE ACCURACY.

Thirty-two waters that were analyzed by Mr. F. M. Eaton were also assayed in the field, and the results of analyses and assays are compared in Table 7. The bicarbonate and carbonate in both sets have been recomputed to CO_3 because changes in the condition of

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the carbonates during the time between assay and analysis make comparison difficult unless this is done. The computation does not affect the accuracy of the results in any way.

TABLE 7.—*Comparison of field and laboratory results of the examination of 32 waters from San Joaquin Valley.*

[Parts per million.]

No.	Carbonate radicle (CO_3).		Sulphate radicle (SO_4).		Chlorine (Cl).		Total hardness as $CaCO_3$.	
	Field.	Laboratory.	Field.	Laboratory.	Field.	Laboratory.	Field.	Laboratory.[a]
1	24	25	5	0	10	5.4	41	48
2	34	35	Tr.	2.9	5	6.0	51	47
3	37	39	Tr.	0	10	8.0	59	51
4	36	40	10	8.2	15	14	40	42
5	40	44	Tr.	0	30	25	63	76
6	60	66	Tr.	0	10	5.9	84	80
7	50	38	Tr.	0	25	22	87	40
8	67	73	Tr.	0	15	15	151	144
9	60	65	Tr.	0	20	15	111	113
10	50	57	5	7.0	35	35	51	56
11	75	78	Tr.	3.7	15	10	122	114
12	63	65	Tr.	4.1	25	22	3	19
13	73	81	5	1.6	20	19	94	94
14	44	44	20	66	50	48	96	122
15	99	103	Tr.	6.6	5	6.0	24	36
16	64	65	Tr.	0	55	51	68	67
17	80	92	Tr.	0	35	35	44	59
18	87	83	55	45	55	58	250	160
19	46	45	Tr.	0	110	112	28	28
20	147	159	Tr.	0	20	22	11	26
21	115	101	10	0	65	64	68	71
22	185	198	5	4.9	280	279	28	31
23	87	95	395	541	115	128	80	91
24	75	70	52	45	470	433	505	450
25	72	76	800	713	85	86	810	754
26	82	96	764	600	165	153	953	698
27	88	94	828	711	125	122	854	1,027
28	77	68	471	441	445	481	162	120
29	828	962	Tr.	0	490	492	535	655
30	101	108	1,640	718	210	196	1,220	1,240
31	860	841	5	0	1,380	1,418	59	30
32	38	42	5	0	4,110	4,310	1,838	2,773

[a] Computed from values for calcium and magnesium.

In Eaton's tests 100 cubic centimeters of water was evaporated to dryness, and the residue was dried at 180° C. for estimation of dissolved solids. Iron was estimated colorimetrically and calcium and magnesium gravimetrically in that residue. Carbonate, bicarbonate, and chloride were determined by titration in ordinary manner, and sulphate by precipitating and weighing as barium sulphate the sulphate in 100 cubic centimeters of the sample. The content of the alkalies, expressed as parts per million of sodium, was computed from these estimates by means of the following formula. The symbols represent the amounts in parts per million of the radicles, and their respective coefficients are obtained by dividing their valences by their molecular weights.

$$Na = 23(0.0333CO_3 + 0.0164HCO_3 + 0.0208SO_4 + 0.0282Cl - 0.0499Ca - 0.0821Mg).$$

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The two sets of carbonate determinations in Table 7 show numerical differences ranging from 0 to 134; only one set, however, has a relative difference exceeding 14 per cent and the average difference of the other 31 sets is 7 per cent. This is not unreasonable in view of the better light and other facilities in the laboratory, and it should be remembered also that all the figures are results of single determinations with unusually small quantities of water. The usual error in the determinations of low chlorines by field assay is 5 parts or less because most of the estimates were performed with 50 cubic centimeters of water. The average difference of the 11 sets of figures exceeding 100 parts per million is less than 6 per cent. Evidently field estimates of chlorine should be expressed not more exactly than to the nearest 5 parts per million and not more than three significant figures should be given.

As total hardness was not determined in the laboratory, a comparative figure has been calculated from the amounts of calcium and magnesium by means of the following formula, in which H, Ca, and Mg represent respectively total hardness as $CaCO_3$, calcium, and magnesium in parts per million:

$$H = 2.5\ Ca + 4.1\ Mg.$$

Though this formula expresses the theoretical relation between the amounts of calcium and magnesium and the hardness found by titration with soap and conventionally expressed as $CaCO_3$ actual determinations do not agree exactly, because the soap titration is subject to obscure errors and because the form of computation magnifies errors in the estimates of the bases. Yet review of the columns showing total hardness indicates that the results obtained by titration convey an approximate idea of the amount of the alkaline-earth bases, though the proportionate differences of single determinations are fairly high. Possibly more nearly accurate estimates could have been made by using a weaker soap solution and greater dilutions.

The estimates of appreciable amounts of sulphate are too few to permit computation of a probable error, but it is apparent that the procedure gives estimates near enough to the correct values for use in approximate classification. The field estimate of sulphate in set No. 14 is obviously incorrect, and other computations indicate that the laboratory report of sulphate in set No. 30 is one-half what it should be.[1]

[1] See also Dole, R. B., The field assay of water: Eng. News, vol. 64, p. 145, 1910; Rapid examination of water in geologic surveys of water resources: Econ. Geology, vol. 6, June, 1911.

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INTERPRETATION OF RESULTS.

For the purpose of ascertaining how much dependence may be placed on field assays—that is, how interpretations of them compare with those of examinations more carefully made and also how far such interpretations agree with practical experience in using the waters in question—certain values have been computed from the data of the 32 analyses and assays of the same waters in Table 7, and notes have been made of the known uses of the waters. The values in the columns headed "Field," in Table 8, are calculated from the assays and in those headed "Laboratory," from Eaton's more complete analyses, except the figure for total solids in the laboratory results, which was obtained directly by weighing the residue dried at 180° C. The computations and classifications are made by means of formulas and ratings explained on pages 50–82.

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TABLE 8.—*Comparison of ratings by field assays and by laboratory analyses.*

[Parts per million except as otherwise designated.]

No.	Computed values.										Classification.								Remarks.
	Total solids.		Scale-forming ingredients (s).		Foaming ingredients (f).		Probability of corrosion[b] (c).		Alkali coefficient (inches).		Mineral content.		Chemical character.		Quality for irrigation.		Quality for boiler use.		
	Field.	Laboratory.[a]	Field.	Laboratory.	Field.	Laboratory.	Field.	Laboratory.	Field.	Laboratory.	Field.	Laboratory.	Field.	Laboratory.	Field.	Laboratory.	Field.	Laboratory.	
1	120	138	90	90	30	3	N.C.	?	140	400	Low..	Low..	$Ca\text{-}CO_3$..	$Ca\text{-}CO_3$..	Good.	Good.	Good....	Good....	Irrigates garden.
2	120	178	100	90	15	30	N.C.	N.C.	200	85	...do..	Moderate.	...do....	...do....	...do .	...do .	Fair.....	...do....	Used for bottle washing
3	130	150	110	95	50	30	N.C.	N.C.	45	70	...do..	Low..	...do....	...do....	...do .	...do .	...do....	Fair.....	Used in boilers and for beer making.
4	150	140	90	90	70	70	N.C.	N.C.	40	40	...do..	...do..	$Na\text{-}CO_3$.	$Na\text{-}CO_3$.	...do .	...do .	Good....	Good....	Domestic use and for stock.
5	170	200	110	125	50	40	N.C.	N.C.	70	80	Moderate.	Moderate.	$Ca\text{-}CO_3$..	$Ca\text{-}CO_3$..	...do .	...do .	Fair.....	Fair.....	Irrigates alfalfa.
6	170	180	130	115	40	50	N.C.	N.C.	55	40	...do..	...do..	...do....	...do....	...do .	...do .	...do....	...do....	Used in boilers and for wine making.
7	180	168	140	85	40	70	N.C.	N.C.	80	37	...do..	...do..	...do.....	$Na\text{-}CO_3$.	...do .	...do .	...do....	Good....	Domestic use and for stock.
8	190	225	200	180	0	0	?	?	140	140	...do..	...do..	...do....	$Ca\text{-}CO_3$..	...do .	...do .	...do....	...Fair....	Irrigates fruit trees.
9	190	210	160	150	30	20	N.C.	N.C.	100	140	...do..	...do..	...do.....	...do.....	...do .	...do .	...do....	...do....	Irrigates grapes and alfalfa.
10	200	218	100	110	120	120	N.C.	N.C.	50	22	...do..	...do..	$Na\text{-}CO_3$.	$Na\text{-}CO_3$..	...do .	...do .	...do....	...do....	Domestic use and for stock.
11	210	210	170	150	30	45	N.C.	N.C.	140	60	...do..	...do..	$Ca\text{-}CO_3$..	$Ca\text{-}CO_3$..	...do .	...do .	...do....	...do....	Not used.
12	200	202	55	65	190	150	N.C.	N.C.	11	14	...do..	...do..	$Na\text{-}CO_3$.	$Na\text{-}CO_3$.	Fair..	Fair..	...do....	Good....	Irrigates alfalfa.
13	220	200	140	135	80	80	N.C.	N.C.	30	27	...do..	...do..	$Ca\text{-}CO_3$..	$Ca\text{-}CO_3$..	Good.	Good.	...do....	Fair.....	Irrigates garden.
14	240	364	150	180	90	110	?	?	40	40	...do..	...do..	...do.....	$Ca\text{-}SO_4$..	...do .	...do .	...do....	...do....	Locomotive supply.
15	230	266	70	90	200	190	N.C.	N. C.	9	10	...do..	...do..	$Na\text{-}CO_3$.	$Na\text{-}CO_3$.	Fair..	Fair..	...do....	...do....	Domestic use and for stock.
16	250	232	120	120	160	140	N.C.	N.C.	16	19	...do..	...do..	...do.....	...do.....	...do..	Good.	...do....	...do....	Do.
17	250	220	90	110	190	180	N.C.	N.C.	11	12	...do..	...do..	...do.....	...do.....	...do..	Fair..	...do....	...do....	To be used on alfalfa.
18	370	344	300	180	40	40	?	?	35	35	...do..	...do..	$Ca\text{-}CO_3$..	$Ca\text{-}CO_3$..	Good.	Good.	Poor.....	...do....	Domestic use and for stock.
19	310	312	80	80	280	260	N.C.	N.C.	10	11	...do..	...do..	Na-Cl....	Na-Cl....	Fair..	Fair..	Bad.....	Bad.....	Irrigates wheat and alfalfa.
20	340	386	60	75	360	340	N.C.	N.C.	5	5.6	...do..	...do..	$Na\text{-}CO_3$.	$Na\text{-}CO_3$.	Poor.	Poor.	...do....	...do....	Supplies watering trough.
21	370	350	120	90	310	230	N.C.	N.C.	7	10	...do..	...do..	...do.....	...do.....	Fair..	Fair..	...do....	Fair.....	City supply.
22	810	872	60	60	920	860	N.C.	N.C.	3	2.9	High..	High..	Na-Cl....	Na-Cl....	Poor.	Poor.	Very bad	Very bad	Said to kill vegetation.
23	950	1,268	110	125	860	1,000	N.C.	N.C.	6	9	...do..	...do..	$Na\text{-}SO_4$.	$Na\text{-}SO_4$.	Fair..	Fair..	...do....	...do....	Irrigates lawn and shade trees; softened for boiler use.

[a] Determined values.

[b] N. C.=Noncorrosive; C.=corrosive; ?=corrosive tendency unknown.

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TABLE 8.—*Comparison of ratings by field assays and by laboratory analyses.*—Continued.

No.	Computed values.										Classification.								
	Total solids.		Scale-forming ingredients (s).		Foaming ingredients (f).		Probability of corrosion (c).		Alkali coefficient (inches).		Mineral content.		Chemical character.		Quality for irrigation.		Quality for boiler use.		Remarks.
	Field.	Laboratory.	Field.	Laboratory.	Field.	Laboratory.	Field.	Laboratory.	Field.	Laboratory.	Field.	Laboratory.	Field.	Laboratory.	Field.	Laboratory.	Field.	Laboratory.	
24	1,000	1,118	530	400	460	400	?	C.	4	4.7	High	High	Ca Cl	Ca Cl	Poor	Poor	Very bad	Very bad	[illegible]
25	1,500	1,702	840	600	360	290	C.	C.	10	20	do	do	$CaSO_4$	$CaSO_4$	Good	Good	do	do	[illegible]
26	1,600	1,392	980	580	270	380	C.	C.	12	12	do.	do	do	do	Fair	Fair	do	Bad	[illegible]
27	1,600	1,826	880	830	440	50	C.	C.	14	17	do.	do	do	do	do	do	do	Very bad	[illegible]
28	1,600	1,616	190	150	1,500	1,400	?	?	4	4.2	do	do	Na Cl	Na Cl	Poor	Poor	do	do	[illegible]
29	2,300	2,452	560	450	2,100	2,000	N. C.	N. C.	1.1	1.1	Very high	Very high	$NaCO_3$	$NaCO_3$	Bad	Bad	do	do	[illegible]
30	3,000	3,210	1,300	980	1,300	0	C.	C.	6	10	do	do	$CaSO_4$	$CaSO_4$	Fair	Fair	do	do	[illegible]
31	3,800	3,930	90	60	4,500	4,200	N. C.	N. C.	.5	.6	do	do	Na Cl	Na Cl	Bad	Bad	do	do	[illegible]
32	6,800	7,489	1,900	2,590	5,400	4,200	C.	C.	.5	.5	do	do	do	do	do	do	do	do	Do

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Nearly all the numerical differences in the computed amounts become insignificant when the values are interpreted according to the ratings that are discussed on pages 50–82. For example, the difference between the alkali coefficients of the first two waters is very great, but as any value exceeding 18 indicates a water good for irrigation the discrepancy of the computed coefficients is negligible. The coefficients agree more closely as the concentration of the mineral matter increases so that the two sets of figures are nearly alike for the poorer waters. The distinction in set No. 16, which is the only pair in which a difference of interpretation occurs, is due only to strict application of the rating according to which the coefficient, 18, is the dividing line between "good" and "fair" waters. The notes under "Remarks" show that the classification coincides with experience in applying the waters to crops. Five of those rated as good for irrigation and four of those rated as fair have been used for several years on various cultures without apparent trouble. No. 17, rated as fair, is to be used for irrigating alfalfa. No. 25, a calcium sulphate water high in mineral matter but rated as good for irrigation, has been used on a variety of small cultures for one year without apparent harm, while it is said that No. 30, which is in the same neighborhood but is distinctly more highly mineralized, can be used to irrigate nothing but alfalfa, probably an old growth. No. 22, classed as poor, is on an abandoned farm, but it is reported to have been unsuccessfully used for irrigating grain. None of the other supplies rated as poor or bad is applied to crops. Many of the differences in the computed values of scale-forming and foaming constituents become insignificant in classification, yet five sets show distinction in class; the differences in sets Nos. 2, 12, and 21 are caused by strict application of the rating tables to estimates that are rather close to the lines of division, and they illustrate well the difficulty that is always experienced in attempting to translate the figures of an analysis into descriptive adjectives. For example, the small difference of 10 parts per million in the estimates of scale-forming ingredients in set No. 2 changes the classification. No importance can be attached to the difference between 3 and 30, the estimated amounts of foaming constituents in the first water, because both numbers are far below the point where the foaming tendency must be considered; similarly, the numerically large discrepancy in corresponding values for No. 23 has no practical significance as either estimate indicates that the water would foam badly. An incorrect determination of total hardness is responsible for the difference in the computed values of the foaming constituents in No. 27, and an unexplained but obvious difference in the estimates of sulphate accounts for a like difference in No. 30, but neither pre-

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vents proper classification of the waters in respect to their value for boiler use. The computed amounts of total solids agree well with those determined by weighing, except in No. 14, where the difference in classification is traceable to the difference in sulphate already mentioned.

Altogether this comparison demonstrates one of the many practical purposes for which rapid methods of water-testing are economical—for selecting waters that are extremely good or extremely bad, thus greatly reducing the number of samples that must be sent to the laboratory for detailed and much more expensive analysis. Field assays afford estimates of much practical value when they are interpreted by the broad standards proper for water ratings, though they can never rival complete analyses in accuracy or in general availability. The comparative inexpensiveness of the assay opens a large and legitimate field of activity, for by means of it agriculturists, geologists, chemists, and others engaged in water investigations can obtain information regarding mineral constituents general in character but essentially practical. The rapidity with which the assays can be made makes it possible to perform the large number of examinations necessary in studying the quality of water over any extensive area.

PROCEDURES OF THE SOUTHERN PACIFIC CO.

A large proportion of the miscellaneous analyses were performed in the laboratory of the Southern Pacific Co. at Sacramento. By the procedures of that laboratory the residue from 1,000 cubic centimeters of the sample, after having been dried at 160° C. to a constant weight, is separated into a soluble and an insoluble portion by treatment with 150 cubic centimeters of hot distilled water. Silica, calcium, and magnesium are estimated in each portion, and the alkalies in the soluble portion are calculated by difference. Chloride, sulphate, nitrate, and carbonate are estimated in separate portions of water by common methods. The results of these tests, stated by the analyst in the form of compounds, have been computed to ionic form in parts per million in order that they may be comparable with other tests.

STANDARDS FOR CLASSIFICATION.

MINERAL CONSTITUENTS OF WATER.

All natural waters contain dissolved or suspended materials with which they have come into contact. They take up such materials in amounts determined principally by the chemical composition and physical structure of the substances, by the temperature, pressure, and duration of their contact, and by the condition of substances that they have previously incorporated. For purposes of examination

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the substances that may be present in natural waters are classified as suspended matter, such as particles of clay or leaves; dissolved matter, either of mineral or organic origin; microscopic animals or plants; and bacteria. The presence of very small animals and plants likely to affect the quality of water is determined by microscopic examination, and the chance of contracting disease by drinking the water is ascertained by bacteriologic processes. The amount and nature of the mineral ingredients are most commonly determined by estimating the total suspended matter, total dissolved matter, total hardness, total alkalinity, silica, iron, aluminum, calcium, magnesium, sodium, potassium, carbonate, bicarbonate, sulphate, nitrate, chloride, free carbonic acid, and free hydrogen sulphide, these being the materials most commonly present and most likely to affect the value of the waters.

WATER FOR IRRIGATION.

SOURCE OF ALKALI.

Many mineral substances are injurious to vegetation, but the only ones that are usually abundant enough to demand attention are compounds of sodium, or, as they are commonly termed, "the alkalies." Though potassium in nominal quantity is a plant food, it is usually not separated from sodium in commercial analyses of water, the two bases being estimated together and reported as sodium; but as the proportion of potassium in highly mineralized waters is commonly low compared with that of sodium this disregard of potassium does not lead to any considerable error in judging the value for irrigation. During the natural decomposition or rotting of rocks and soils salts of the alkalies, easily soluble in water, are formed. These compounds are leached from the soil and washed away in regions where plenty of rain falls, and consequently they do not become concentrated enough to damage crops; but wherever the rainfall is insufficient to effect this removal such materials continually increase, and the proportion of them may become so great that plants are stunted or killed and the ground becomes unproductive.

Accumulations of alkali can also be caused in another way. All waters that penetrate the ground either naturally or as a result of irrigation contain these salts in solution, and evaporation of the water, leaving the salts, adds to the supply that has been formed by decomposition of rock. Such concentration of soluble salts has been taking place for a long time in the basin of Tulare Lake, the waters of which have been removed many times by evaporation, leaving a residue of salts to mix with those already in the ground. The effect of waters applied during irrigation is all that is properly within the scope of this section, but certain general features in connection with

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the occurrence of alkali should be considered, because the soluble salts normally formed in the soil and those introduced by the water are alike in their nature and their effect.

OCCURRENCE OF ALKALI.

The soluble salts are not evenly distributed over an area or through a given depth, but are ordinarily concentrated in patches near the surface. Such patches may be found in slight depressions into which mineralized water has seeped or drained and from which it has later evaporated. The underground water drawn to the surface by capillarity also brings alkali, which becomes concentrated in the upper layers of the soil. Where the salts are largely sulphates or chlorides the plots are covered with deposits of so-called "white alkali"—that is, crystals of alkaline chlorides and sulphates, mostly common salt and Glauber's salt; but when much carbonate is present the plots are blackened by solution of humus and are termed spots of "black alkali." It can readily be understood from the manner in which the salts are formed and from the possibility of their introduction by seepage or irrigation that the alkali content of a soil can progressively increase until it reaches a strength that will destroy plants previously unaffected. Conversely, a soil that is normally too high in alkali can be rendered productive by washing part of the soluble salts out of it.

If the alkali content of a soil is excessive the growth of cultures is retarded or entirely prevented. A still greater amount of salts kills the most resistant plants, and the area becomes devoid of vegetation. The chief cause of the poisonous action is commonly considered to be abstraction of water from the plant roots by change of the osmotic pressure, but bad effects are also probably more or less due to corrosion of the plant roots, germicidal action on the soil bacteria, and interference with the food supply through solution of humus.

PERMISSIBLE LIMITS OF ALKALI.

The cause and the manner of the harmful action are, however, not so important at present as the amount of these toxic compounds that can be tolerated by crops, for the limit of resistance in soils fixes in turn the maximum content of waters that can safely be used for irrigation, and it indicates the precautions that must be taken in applying the water. Yet it becomes evident from brief consideration of the problem that limits of tolerance must be very broadly interpreted and that absolute classification of waters in respect to their irrigation value is impracticable.

Many investigators have studied the effect on plant growth of mineral substances in water solutions, and the excellent work of Kearney

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and Cameron [1] is typical of these. Experimenting with seedlings of white lupine and alfalfa in different strengths of pure solutions, they found that the readily soluble salts common in soils are toxic in the following order: Magnesium sulphate, magnesium chloride, sodium carbonate, sodium sulphate, sodium chloride, sodium bicarbonate, and calcium chloride, the first being 200 times as harmful as the last. But when similar tests were made in the presence of an excess of calcium sulphate and calcium carbonate both the order of toxicity and the maximum concentrations in which the seedlings would grow were entirely changed. The order and the limits for lupine under these conditions are sodium carbonate, 1,560 parts per million; sodium bicarbonate, 4,170 parts; magnesium chloride, 9,600; sodium chloride, 11,600; calcium chloride about 16,000; sodium sulphate, 21,600; and magnesium sulphate, 22,400. Magnesium sulphate, which is most toxic in pure solution, is least harmful in the presence of large amounts of calcium carbonate and sulphate. The chlorides of magnesium, sodium, and calcium follow each other in relative toxicity. The sulphate was found to be the least harmful of the sodium salts, sodium chloride being twice and the carbonate fourteen times as poisonous. These alterations are extremely significant, for none of the salts occurs in large amount in soils except in the presence of large quantities of calcium and more or less of all the other harmful salts. Therefore the death point in a simple solution of one salt is not a safe measure of tolerance, for the power of resistance under natural conditions depends on complex reactions between all the components of the soil solution.

Other investigators have shown not only that different cultures have different degrees of resistance but also that the order of toxicity of the various salts is changed. Some species of rather weak tolerance have also been bred to withstand high concentrations, and it is a matter of ordinary observation in regions of alkali that certain crops die on land where others flourish. The vertical position of the soluble salts also is important. Where, as under ordinary conditions, they are concentrated near the surface they can do the greatest amount of damage because they are in contact with the delicate roots. But they may be washed downward out of the danger zone by proper application of water. All these considerations make it evident that the nature of the crops, the manner of cultivation and irrigation, the

[1] Kearney, T. H., and Cameron, F. K., Some mutual relations between alkali soils and vegetation: U. S. Dept. Agr. Rept. 71, 1902.

Cameron, F. K., and Breazeale, J. F., The toxic action of acids and salts on seedlings: Jour. Phys. Chemistry, vol. 8, p. 1, 1904.

Jensen, G. H., Toxic limits and stimulation effects of some salts and poisons on wheat: Bot. Gazette, vol. 43, p. 11, 1907.

Kahlenberg, L., and True, R. H., The toxic action of dissolved salts and their electrolytic dissociation, Bot. Gazette, vol. 22, p. 81, 1896.

Heald, F. D., The toxic effect of dilute solutions of acids and salts upon plants: Bot. Gazette, vol. 22, p. 125, 1896.

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other mineral components of the soil, and many other factors affect tolerance to alkali; when the effects of reactions between the mineral constituents of the soil and of the applied water are added to these modifying features it must be admitted that all general conclusions regarding the potential value of a water supply for irrigation are subject to much modification in particular cases.

Possibly the best basis for conclusions on the value of water for irrigation is the work of Loughridge,[1] who has endeavored to determine the greatest amounts of alkali in the upper 4 feet of ground in the presence of which cultures grow and come to maturity. In pursuance of this plan observations were made of the condition of fruit trees, shrubs, cereals, and other cultivated plants growing or dying in soils, which were then partly analyzed. Loughridge's results are of great practical interest because they are linked with observations on cultures growing under natural conditions on a large scale, and they are here particularly valuable because they represent experiments mostly in the territory covered by this report. Interpretation of the figures is complicated, however, as Loughridge points out, by uncertainty as to whether the observed poor growth was always due to presence of alkali and not to other harmful conditions. As not one alone but all the salts are present in natural soils and as they owe their toxic action to the extent to which they are dissociated, the impossiblity of determining the exact amounts of the different salts in solution or the share of each acid and each basic radicle in the toxic action is fully apparent. Notwithstanding these doubtful points much can be learned from the studies regarding the relative tolerance of cultures.

The amount of alkali that could be tolerated was found to depend largely on the distribution of the salts in the vertical soil column, the injury usually being greatest in the upper foot, where the feeding roots and the greatest amount of alkali occurred together. The range of tolerance for different cultures is very great. Lemon trees, considered very sensitive, were unaffected in the presence of 5,760 pounds of alkali per acre 4-feet, while grapevines withstood nearly eight times as much, or 45,760 pounds. Sorghum flourished in soil containing 81,360 pounds per acre 4-feet, but rye withstood only 12,480 pounds of alkali. The fact that some plants are more readily affected when they are young is well illustrated by alfalfa, which tolerates more than eight times as much alkali when old as when young. Experiments in vineyards showed that different varieties are affected to different degree by alkali and as a corollary that alkali changes the composition of grapes.

[1] Loughridge, R. H., Tolerance of alkali by various cultures: California Univ. Agr. Exper. Sta. Bull. 133, 1901. Quoted by Hilgard, E. W., Soils, p. 467, Macmillan Co., New York, 1906. See also California Univ. Agr. Exper. Sta. Bulls. 128, 140, and 169.

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RELATIVE HARMFULNESS OF THE COMMON ALKALIES.

Though various cultures are affected in different degree by sodium in the three common forms of carbonate, chloride, and sulphate, there is some general agreement. Sodium as the carbonate is commonly the most harmful, as the chloride somewhat less so, and as the sulphate least harmful. Hilgard [1] gives the maxima for cereals grown on a certain sandy loam as about 0.1 per cent of sodium carbonate, 0.25 per cent of sodium chloride, and 0.48 per cent of sodium sulphate, corresponding to a toxicity ratio expressed in terms of sodium of 1:1.6:3.6. The relative harmfulness of sodium in the sulphate, chloride, and carbonate, respectively, can be expressed according to Loughridge's results for ten standard crops of San Joaquin Valley by the ratio 1:5:6.6; that is, sodium as the carbonate is 6.6 times as harmful, and sodium as the chloride 5 times as harmful as sodium as the sulphate. A similar ratio for the 15 most sensitive crops is 1:5.3:6.4. If, therefore, sodium as the sulphate is given a toxicity of 1 a reasonably approximate estimate of the relative toxicity of sodium as the sulphate, chloride, and carbonate, respectively, would be expressed by the ratio 1:5:6. Stabler has used in his formulas, quoted later, the ratio 1:5:10 in order to allow for the undesirable puddling of the soil by the carbonate.

RELATION BETWEEN APPLIED WATER AND SOILS.

When water used in irrigating evaporates from the surface of the soil it leaves in the ground its content of salts. If all the applied water were to escape by evaporation, constant use of any supply, no matter how pure it might be, would eventually result in an accumulation of alkali that would render the soil unproductive. If, on the other hand, all of a water not too high in mineral content were to seep downward into the deep-lying strata it would leach out the soluble salts of a highly charged area, which would thus be made productive. Such extreme conditions, however, are not natural. Though evaporation greatly exceeds rainfall in arid regions, and the accumulation of alkali is thus facilitated, part of the water seeping away carries with it a load of salts in solution. Various amounts of mineral matter are also taken up by crops and are removed during harvesting; then, too, the sodium in the soil and in the applied water can be prevented by proper methods of irrigation and drainage from accumulating where it will damage the delicate feeding roots of cultures. Consequently, waters of a relatively low mineral content may be applied year after year without inflicting damage, but those exceeding a certain limit of mineral content are useless for irrigation; waters of an intermediate class, normally capable of increasing the

[1] Hilgard, E. W., Soils, p. 464, Macmillan Co., New York, 1906.

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alkalies in the soil, may be harmless under judicious usage. This outline of the general relations between the saline content of soils and of waters used on them indicates other allowances that should be made in estimating to what extent the mineral matter in applied waters affects their value for irrigation.

NUMERICAL STANDARDS.

Twelve hundred parts per million of mineral matter is the limit of concentration given by Hilgard [1] for irrigation water in all cases under the ordinary practice in California. This limit is greatly modified by the character of the dissolved salts, and the results of extensive irrigation elsewhere indicate that very much stronger waters can be used on some soils if they are properly applied. Basing his computations on Loughridge's determinations of tolerance,[2] Stabler [3] has developed formulas for rating waters in respect to their value for irrigation. His comparison is made by means of an "alkali coefficient" (k), which is defined as the depth in inches of water which would yield on evaporation sufficient alkali to render a 4-foot depth of soil injurious to the most sensitive crops. The sodium equivalents of the three common salts of sodium, the sulphate, chloride, and carbonate, are assigned relative toxicities of 1, 5, and 10, respectively, and the maximum tolerance of sensitive cultures is taken as 1,500 pounds of sodium in the form of sulphate per acre 4-feet. The correctness of the latter assumption by itself might be questioned in view of the fact that Loughridge's figures for cultures at the lower end of his lists are particularly liable to upward revision after further investigation. Yet this should not lead to appreciable error as the chief value of the formulas rests in the ratio of toxicities and the interpretation of the computed value of k.

If $\mathrm{Na} - 0.65\,\mathrm{Cl}$ is zero or negative, $k = \frac{2{,}040}{\mathrm{Cl}}$.

If $\mathrm{Na} - 0.65\,\mathrm{Cl}$ is positive but not greater than $0.48\,\mathrm{SO_4}$, $k = \frac{6{,}620}{\mathrm{Na} + 2.6\,\mathrm{Cl}}$.

If $\mathrm{Na} - 0.65\,\mathrm{Cl} - 0.48\,\mathrm{SO_4}$ is positive, $k = \frac{662}{\mathrm{Na} - 0.33\,\mathrm{Cl} - 0.43\,\mathrm{SO_4}}$.

The alkali coefficient, k, is in inches as already explained; the symbols $\mathrm{SO_4}$, Cl, and Na represent, respectively, the amounts in parts per million in the water of sulphate, chlorine, and alkalies, the latter being commonly grouped under the name of sodium. Consideration of bicarbonate is precluded because estimates of it apparently were not made in the work on which the formulas are based. The three formulas represent the different relations between

[1] Op. cit., p. 248.

[2] Loughridge, R. H., Tolerance of alkali by various cultures: California Univ. Exper. Sta. Bull. 133, 1901.

[3] Stabler, Herman, Some stream waters of the western United States, with chapters on sediment carried by the Rio Grande and the industrial application of water analyses: U. S. Geol. Survey Water-Supply Paper 274, p. 177, 1911. See also Eng. News, vol. 64, p. 57, 1910.

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the alkali and the acid radicles. Under the first condition, with enough, or more than enough, chlorine to satisfy sodium, it is assumed that chlorides other than that of sodium are as harmful as that compound. Cameron[1] found that magnesium chloride, sodium chloride, and calcium chloride had relative toxicities of 1.2: 1.0: 0.6, respectively, in the presence of an excess of calcium sulphate or of calcium sulphate and calcium carbonate. Under the second condition, where the chloride and sulphate radicles together are sufficient to satisfy sodium, and under the third, where both chlorine and sulphate are insufficient to satisfy sodium, magnesium is assumed to have no deleterious effect. This base loses the greater part of its toxic power when much calcium is present and therefore this assumption seems justifiable as not only is calcium usually high in all soils but also it commonly exceeds the proportion of magnesium in natural waters. Though the formulas are based on the relative predominance of the radicles, they should not be interpreted as signifying that the acids and bases are combined but as presenting the maximum possibilities of the deposition of harmful alkali salts in the soil layer. Waters to which the first two formulas are applicable are likely to leave white alkali on evaporation, and those in the third class probably yield black alkali.

The approximate amount of alkali in a water can be computed from the results of a field assay by the following formula:

$$Na = 0.83\ CO_3 + 0.41\ HCO_3 + 0.71\ Cl + 0.52\ SO_4 - 0.5\ H.$$

The symbols represent the amounts in parts per million of alkali (sodium and potassium) and the carbonate, bicarbonate, chlorine, sulphate, and total hardness found by assay. The equation expresses the theoretical relation that the sum of the reacting values of the acid radicles minus the reacting values of calcium and magnesium, which together are one-fiftieth of total hardness, equals the reacting value of the alkalies; the factor 25 instead of 23, the atomic weight of sodium, is used for safety. Because of the approximate nature of the figures of field assays values of k computed from them should be reported with not more than two significant figures and to the nearest 10 when they exceed 30.

The following ratings for interpreting values of the alkali coefficient are proposed by Stabler:

TABLE 9.—*Classification of water for irrigation.*

Value of k.	Classification.
Greater than 18	Good.
6 to 18	Fair.
1.2 to 5.9	Poor.
Less than 1.2	Bad.

[1] Cameron, F. K., and Breazeale, J. F., The toxic action of acids and salts on seedlings: Jour. Phys. Chemistry, vol. 8, p. 1, 1904.

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The value of k, showing the number of inches of water that would yield on evaporation sufficient alkali to inhibit the growth of very sensitive plants, indicates the relative degree of care that is essential in applying a water to irrigated tracts. As defined by Stabler, "good" waters are those that can be used for many years without special care to prevent alkali accumulation. Waters classed as "fair" require special care to prevent gradual concentration of alkali except in loose soils with free natural drainage. In using waters classed as "poor" care in selection of soils has been imperative and artificial drainage has frequently been necessary. The "bad" waters contain so much harmful matter in solution that they are practically valueless for irrigation. These ratings are based on general practice in the arid and semiarid regions of the United States, and so far as they can be checked by comparison with actual experience in the use of waters in San Joaquin Valley they answer all practical purposes.

This rating, like any other that might be devised, should be liberally interpreted. It is well to repeat emphatically that it signifies only a comparison of the waters themselves on the basis of their mineral content. It has no reference whatever to the possibility of raising good crops on land to which the waters may be applied, because it does not take into account the alkali content and the texture of the soil, drainage conditions, the method of irrigation, the duty of the water, or the other factors on which agricultural success depends.

REMEDIES FOR ALKALI TROUBLES.

WASHING DOWN THE ALKALI.

The relation between applied water and soils makes it apparent that the farmer can control the alkali content of his ground to great extent by the manner in which he applies water and the care he takes to prevent accumulation of soluble salts near the surface. When a deep, readily pervious soil is covered with water to a proper depth by flooding, which is widely practiced in San Joaquin Valley, the water rapidly soaks into the soil, dissolving the alkali salts concentrated near the surface and carrying them downward beyond the zone of influence on the delicate feeding rootlets. But if the ground is not then protected against surface evaporation the water is drawn upward and alkali again impregnates the top layers. This action can be prevented in some measure by thorough cultivation as soon as possible after irrigation, and the shade afforded by trees and good stands of grass or grain also minimizes it. This shading effect partly explains why well-established growths of some cultures can thrive in soil containing an amount of alkali injurious to younger crops. A good stand of alfalfa, for instance, inhibits surface evaporation and consequent rise of alkali to the feeding roots, though the ground

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deeper down may contain enough alkali to kill the plants; whereas newly started alfalfa can not prevent evaporation, and the alkali, dissolved by the water and rising with it by capillarity, becomes concentrated where it can do the greatest damage. A shallow soil underlain by hardpan is not benefited by flooding alone, as the leaching is stopped by the impervious layer.

It is a prevalent idea that alkali can be washed from a piece of land by flooding it with large quantities of water and then allowing the surplus to run off. The improvement is, however, not due so much to removal of the comparatively small quantities of material carried away in the off-flow as to depression of the alkali by the downward percolation just described. The results of some experiments by Headden[1] illustrate this well. Two waters, the composition of which is given in columns A and B of Table 10, were used during two successive days to flood a tract of alkali land about 600 feet long. Four samples of the off-flow were taken, two at the beginning of the off-flow and two just before the on-flow was stopped, and the average of the analyses of these four samples is given in column C. Though one of them, taken at the very commencement of the off-flow, carried 1,238 parts per million of dissolved solids, this high content lasted only a few minutes, and comparison of the average with the results in columns A and B shows how little the total mineral content of the water that remained above ground and finally flowed off after crossing the entire area was increased by solution of the alkali in the soil.

TABLE 10.—*Effect of flooding on alkali as shown by composition of water.*

[Parts per million.]

Constituents.	A	B	C	D	E
Total solids	328	706	760	1,415	3,278
Organic and volatile matter	27	37	44	92	145
Silica (SiO_2)	10	14	12	23	20
Oxides of iron and aluminum ($Fe_2O_3+Al_2O_3$)	1.0	3.4	.8	1.6	.7
Calcium (Ca)	43	90	93	139	314
Magnesium (Mg)	10	24	30	66	170
Manganese (Mn)	.6	.8	.2	.7	1.0
Sodium (Na)	42	96	102	195	436
Potassium (K)	3.6	3.8	5.6	1.9	6.4
Carbonate radicle (CO_3)	64	106	112	120	149
Sulphate radicle (SO_4)	113	305	335	713	1,885
Chlorine (Cl)	10	24	24	60	147

A. Water used in irrigating on Sept. 1.
B. Water used in irrigating on Sept. 2.
C. Average composition of off-flow Sept. 2.
D. Average composition of water from 4 shallow wells Aug. 31.
E. Average composition of water from 4 shallow wells Sept. 2.

Four shallow wells in the plot, protected against entrance of water over the top, were sampled before (column D) and after irrigation

[1] Headden, W. P., Colorado irrigation waters and their changes: Colorado Agr. Coll. Exper. Sta. Bull. 82, 1903.

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(column E). The composition of the ground water portrayed by these averages is typical in showing the downward passage of the alkali salts in the soil. The average amount of mineral matter in the off-flow is only slightly greater than that in the applied water that was used in greater quantity, but the water in the wells increased in dissolved solids from 1,415 parts to 3,278 parts per million, calcium, magnesium, sodium, sulphate, and chloride having been more than doubled. Headden estimates that the ground water gained about 5,000 pounds of mineral matter per acre-foot of water by this irrigation.

The effect of natural precipitation in washing down the soluble salts can be illustrated by analyses of water from the same wells after a long period of heavy rainfall. Just before the rain stopped the water of one well contained 10,360 parts per million of total solids, an amount several times the normal; only eight days later solids had fallen to 6,450 parts; and to 2,030 parts after a month. This decided increase of mineral content after rainfall and the subsequent decrease coincident with the loss of water by evaporation and drainage can be explained by change in position of the soluble salts in the soil column.

Irrigation by shallow furrows from which the water soaks into the ground is practiced extensively in orchards and truck gardens throughout San Joaquin Valley. This causes downward transmission of alkali in pervious soils like flooding, with the added advantage that the decreased evaporation lessens the tendency toward surface concentration of alkali. Deep, narrow furrows would undoubtedly still further reduce the proportion of water lost by evaporation and would prevent the rise of alkali by affording deeper circulation of the water supply.

DRAINAGE.

Such downward washing of soluble substances affords no permanent relief, for the alkali, not being removed, may be drawn again to the surface, or may rise as a result of wasteful irrigation, a trouble common in water-logged soils. Downward washing can be safely relied on only when the soils are pervious and have good natural drainage. Application of heavily mineralized water even under such conditions year after year may increase the amount of the harmful ingredients and render them more difficult to handle. The recognized permanent remedy is installation of underdrains, through which the dissolved substances may be removed. The installation of drainage is costly, but it has become an essential part of irrigation systems wherever the soils are very bad or the waters are high in harmful ingredients, for it not only facilitates the removal of the deleterious salts originally in the ground, but also affords means for preventing accumulation of alkali when very strong waters are used.

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The experimental plots cultivated by the Department of Agriculture in Fresno County where the "rise of the alkali" has spoiled otherwise good ground have been thoroughly reclaimed by underdrainage.[1] Many of the waters of the valley now considered poor for irrigation can probably be utilized on well-drained tracts, for sodium chloride waters far more concentrated than some of the poorer ones in the trough of San Joaquin Valley are being successfully applied to Algerian lands[2] that are thoroughly drained. The best results with strong saline waters have been obtained by irrigating copiously at frequent intervals. In conjunction with free drainage such operation prevents concentration of alkali salts in the soil, for any accumulation that may form is quickly dissolved and washed downward.

MISCELLANEOUS REMEDIES.

Though it is possible to remove a large proportion of the alkali crust by scraping the surface of the land that method is too expensive to be generally adopted. Growing and completely cropping plants that secrete relatively large quantities of alkali is tedious but fairly successful. The injurious effect of carbonate alkali can be greatly reduced by spreading the ground with gypsum, by action of which carbonate of lime and alkali sulphates are formed. As carbonate alkalies are much more harmful than chlorides or sulphates treatment of this character lessens the toxic action.

WATER FOR BOILER USE.

FORMATION OF SCALE.

The most common trouble in boilers is formation of scale, or deposition of mineral matter within the boiler shell. When water is heated under pressure and concentrated by evaporation, as in a boiler, certain substances are thrown out of solution and solidify on the flues and crown sheets or within the tubes. These deposits increase fuel consumption because they are poor conductors of heat and increase the cost of boiler repairs and attendance because they have to be removed. If the amount of scale is great or if it is allowed to accumulate the boiler capacity is decreased and disastrous explosions are likely to occur.

The incrustation (scale) consists of the substances that are insoluble in the feed water or become so within the boiler under conditions of ordinary operation. It includes practically all the suspended matter, or mud; the silica, probably precipitated as the oxide (SiO_2); the iron and aluminum, appearing in the scale as oxides or hydrated

[1] Fortier, Samuel, and Cone, V. M., Drainage of irrigated lands in the San Joaquin Valley, California: U. S. Dept. Agr. Exper. Sta. Bull. 217, 1909.

[2] Means, T. H., The use of alkaline waters for irrigation: U. S. Dept. Agr. Bur. Soils Circ. 10, 1903; also U. S. Geol. Survey Water-Supply Paper 93, p. 255, 1904.

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oxides; the calcium, precipitated principally as carbonate and sulphate; and the magnesium, found chiefly as oxide but also partly as carbonate. Scale is therefore a mixture, which varies in amount, density, hardness, and composition with the quality of water supply, the steam pressure, the type of boiler, and other conditions of use. Calcium and magnesium are the principal basic substances in the scale, over 90 per cent of which usually is calcium, magnesium, carbonate, and sulphate. If much organic matter is present part of it is precipitated with the mineral scale, as the organic matter is decomposed by heat or by reaction with other substances. If magnesium and sulphate are comparatively low or if suspended matter is comparatively high the scale is soft and bulky and may be in the form of sludge that can be blown or washed from the boiler. On the other hand, a clear water relatively high in magnesium and sulphate may produce a hard, compact scale that is nearly as dense as porcelain, clings to the tubes, and offers great resistance to the transmission of heat. Therefore the value of a water for boiler use depends not only on the quantity but also on the physical structure of the scale produced by it.

CORROSION.

Corrosion or "pitting" is caused chiefly by the solvent action of acids on the iron of the boiler. Free acids capable of dissolving iron occur in some natural waters, especially in the drainage from coal mines, which usually contains free sulphuric acid, and also in some factory wastes draining into streams. Many ground waters contain free hydrogen sulphide, a gas that readily attacks boilers, and some contain dissolved oxygen and free carbon dioxide, which are also corrosive. Organic matter is probably a source of acids, for waters high in organic matter and low in calcium and magnesium are corrosive, though the nature and action of the organic bodies are not well understood. The chief corrosives are acids freed in the boiler by the deposition of hydrates of iron, aluminum, and magnesium, the last-named being the most important as it is the most abundant. The acid radicles that were in equilibrium with these bases may pass into equilibrium with other bases, displacing equivalent quantities of carbonate and bicarbonate; or they may decompose carbonates that have been precipitated as scale; or they may combine with the iron of the boiler, thus causing corrosion; or they may do all three, their action depending on the chemical composition of the water. Even with the most complete analyses this action can be predicted only as a probability. If the acid thus freed exceeds the amount required to decompose the carbonate and bicarbonate radicles it attacks the iron of the boiler and produces pits or tuberculations of the interior surface, leaks, particularly around rivets, and general deterioration.

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FOAMING.

Foaming is rising of the water in the boiler and particularly in the steam space normally above the water, and it is intimately connected with priming, which is the passage from the boiler of water mixed with steam. Foaming results when anything prevents the free escape of steam from the water. It is usually ascribed to an excess of dissolved matter that increases the surface tension of the liquid and thereby reduces the readiness with which the steam bubbles break. As sodium and potassium remain dissolved in the boiler water while the greater portion of the other bases is precipitated, the foaming tendency is commonly measured by the degree of concentration of the alkali salts in solution, because this figure in connection with the type of boiler determines to great extent the length of time that a boiler may run without danger of foaming. It is a fact that the worst foaming waters in railroad practice are encountered in the arid and semiarid regions of the Southwest where the quantity of dissolved alkali is greatest. However, it is well known that suspended matter can cause foaming, for certain waters that deposit a moderate amount of scale but do not foam when clear foam badly when they carry a great quantity of mud. Greth [1] states that foaming is due to condition of boiler, design of boiler, size and shape of water space, steam pipe, irregularity in blowing off, introduction of oil into the feed water from the exhaust steam, neglect to change water periodically, irregularity of load, or improper firing and feeding. He concludes that it is not merely the presence of sodium salts in solution that causes foaming, but the presence of other substances which together with the sodium salts and operating conditions bring about foaming. The writer believes that a strong solution of sodium carbonate might not induce excessive foaming in water otherwise pure, but its introduction into a boiler, which under operating conditions invariably contains suspended matter or precipitated sludge, might produce foaming by increasing the suspended matter either by precipitating calcium and magnesium or by loosening previously deposited scale. Under working conditions it is difficult to distinguish the actual cause of the trouble. Experience has shown that the type of boiler, steam pressure, and other operating conditions may greatly accelerate or retard foaming.

REMEDIES FOR BOILER TROUBLES.

The best way of remedying unsatisfactory boiler supplies is to treat them before they enter boilers, but where this is impracticable trouble can be minimized in various ways. Low-pressure large-flue

[1] Greth, J. C. W., Water softening and purification for coal-mine operations (paper read before the West Virginia Coal Mining Institute, Bluefield, W. Va., June 7, 1910).

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boilers are used in many stationary plants with hard waters, and it is said that the scale formed in them is softer and more flocculent and can therefore be more readily removed than that formed in high-pressure boilers. Blowing off is about the only practical means of preventing foaming, because this trouble is due principally to concentration of substances in the residual water of the boilers. Accumulated sludge, or soft scale, is removed by blowing, particularly in locomotive practice. In condensing systems much of the trouble due to mineral matter in the feed water is obviated because the quantity of raw water supplied is proportionately small. Yet the problem is not completely solved in such systems, because the incrusting or corrosive action is transferred from the boiler to the condenser, which requires more or less cleaning and repairing in proportion to the undesirable qualities of the water supply.

BOILER COMPOUNDS.

Boiler compounds are widely used in regions where hard waters abound, but treatment within the boiler should be given only when it is impossible to purify the supply beforehand or when the supply is relatively pure and requires only minor correction. If previous purification is not practicable some feed waters can be improved by judicious addition of chemicals. Many substances, ranging from flour, oatmeal, and sliced potatoes to barium and chromium salts, have been recommended for such use, but only a few have proved to be really efficient. These substances have been classified [1] according to their action within the boiler. Those that attack chemically the scaling and corroding constituents precipitate incrusting matter and neutralize acids. Soda ash, the commercial form of sodium carbonate, containing about 95 per cent Na_2CO_3, is the most valuable substance of this character, because it is cheap and its use is attended with the least objectionable results. Tannin and tannin compounds are also used for the same purpose. The addition of limewater to the feed to prevent corrosion and to obviate foaming has been recommended,[2] and it is probable that it would improve waters high in organic matter and very low in incrustants. Such practice increases the incrustants in proportion to lime added but prevents corrosion. Soda ash neutralizes free acids, precipitates the incrusting ingredients as a softer, more flocculent material, which is more easily removed from the boiler, and increases the foaming tendency of the water by increasing its content of dissolved matter. The proper amount to be used depends on the chemical composition of the water and the style of the boiler.

[1] Cary, A. A., The use of boiler compounds: Am. Machinist, vol. 22, pt. 2, p. 1153, 1899.

[2] Palmer, Chase, Quality of the underground waters in the Blue Grass region of Kentucky: U. S. Geol. Survey Water-Supply Paper 233, p. 187, 1909.

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The second class of boiler compounds comprises those that act mechanically on the precipitated crystals of scale-making matter soon after they are formed, surrounding them and robbing them of their cement-like action. Glutinous, starchy, and oily substances belong to this class, but they are not now used to any considerable extent because they thicken and foul the water more than they prevent the formation of hard scale.

The third class comprises compounds that act mechanically like those of the second class and also partly dissolve deposited scale, thus loosening it and aiding in its ready removal. Of these, kerosene is very effective, but graphite is believed to be still better.

Many boiler compounds possessing or supposed to possess one or more of the functions just described are on the market and are widely sold. Some are effective and some are positively injurious. Most of them depend for their chief action on soda ash, petroleum, or a vegetable extract, but all are costly compared with lime and soda ash. Boiler compounds can not reduce the amount of scale and may increase it. Their only legitimate functions are to prevent corrosion and deposition of hard scale and to remove accumulations of scale that have become attached to the boiler. Every engineer should bear in mind that steam boilers are costly and that fuel and boiler repairs are costly and should hesitate to add substances to his feed water without competent advice as to their effect. It is far more economical to have the water supply analyzed and to treat it effectively by well-known chemicals in proper proportion, either within or without the boiler, than to experiment with compounds of unknown composition.

NUMERICAL STANDARDS.

Stabler's excellent mathematical discussion of the quality of waters with reference to industrial uses [1] contains several formulas by which the effect of waters may be computed. They have been recalculated in order to obtain the estimates in parts per million. The terms involving iron, aluminum, and free acids have been omitted because these substances are too scarce to call for consideration in such approximate rating; and the terms involving sodium and potassium have been united for simplicity.

(1) $s = Sm + Cm + 2.95\ Ca + 1.66\ Mg$

(2) $h = SiO_2 + 1.66\ Mg + 1.92\ Cl + 1.42\ SO_4 - 2.95\ Na$

(3) $f = 2.7\ Na$

(4) $c = 0.0821\ Mg - 0.0333\ CO_3 - 0.0164\ HCO_3$.

These equations express numerically some of the relations that have been discussed in the preceding sections on scale, corrosion, and

[1] Stabler, Herman, Some stream waters of the western United States, with chapters on sediment carried by the Rio Grande and the industrial application of water analyses: U. S. Geol. Survey Water-Supply Paper 274, p. 165, 1911. See also Eng. News, vol. 60, p. 355, 1908.

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foaming. Sm, Cm, SiO_2, Ca, Mg, Na, Cl, SO_4, CO_3, and HCO_3 represent the amounts in parts per million, respectively, of suspended matter, colloidal matter (oxides of silicon, iron, and aluminum), silica, calcium, magnesium, alkalies, chlorine, sulphate, carbonate, and bicarbonate.

Formula 1 gives the amount of scale (s) that would probably be formed from the water under ordinary conditions of boiler operation; as the ground waters of San Joaquin Valley are practically clear, Sm is equal to zero. Cm has been given a value of 50 for waters not exceeding 400 parts of total solids and 30 for other waters, and these values may be considered large enough for safety.

Formula 2 gives the amount of hard scale forming ingredients (h). The ratio $\frac{h}{s}$ expresses the relative hardness of the scale. If $\frac{h}{s}$ is greater than 0.5 the scale may properly be called hard; if it is less than 0.25 the scale may properly be called soft.

Scale (s) has been estimated from the data of the field assays by adding to total hardness (H) the values of Cm used in formula 1 ($s = Cm + H$). As H theoretically equals 2.5 Ca + 4.1 Mg, and the last two terms of equation 1 are 2.95 Ca + 1.66 Mg, the unknown but variable ratio between calcium and magnesium introduces an uncertain error. Estimates of the scale-forming constituents are, however, always approximate, and experience indicates that this computed value is accurate enough for relative ratings.

Formula 3 gives the amount of the foaming ingredients (f), as estimated from the probable content of alkali salts. The value of sodium (Na) computed by the formula on page 57 has been used in computing the amount of the foaming ingredients from the results of the field assays.

Formula 4 has been used to calculate the corrosive tendency of the water (c). As can be readily seen from the coefficients, it expresses the relation between the reacting values of magnesium and the radicles involving carbonic acid (p. 62). If c is positive, the water is corrosive. If c + 0.0499 Ca, the reacting value of calcium, is negative, the mineral constituents will not cause corrosion, but whether organic matter or electrolysis will cause it is uncertain. If c + 0.0499 Ca is positive corrosion is uncertain. These conditions of reaction may be restated to conform to the data of the field assays thus: If 0.033 CO_3 + 0.016 HCO_3 equals or exceeds 0.02 H the mineral constituents will not cause corrosion. If 0.004 H exceeds 0.033 CO_3 + 0.016 HCO_3 the water is corrosive. One-fiftieth of the total hardness (0.02 H) is equivalent to the reacting value of calcium and magnesium, and H divided by 230 (0.004 H) is equivalent to the reacting value of magnesium on the assumption that Ca = 6 Mg, a ratio in which magnesium is given its smallest probable value in relation to

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calcium. The reacting values of carbonate and bicarbonate are represented, respectively, by 0.033 CO_3 and 0.016 HCO_3, the coefficients of which are obtained by dividing the valence of each radicle by its molecular weight.

After these three attributes of boiler feed have been computed rating the water is largely a matter of judgment based on experience. The committee on water service of the American Railway Engineering and Maintenance of Way Association has offered two classifications by which waters in their raw state may be approximately rated, but, as the report states, "it is difficult to define by analysis sharply the line between good and bad water for steam-making purposes." Table 11 gives these classifications with the amounts transformed to parts per million.

TABLE 11.—*Ratings of waters for boiler use according to proportions of incrusting and corroding constituents and according to foaming constituents.*

Incrusting and corroding constituents.			Foaming constituents.		
Parts per million.		Classification.[a]	Parts per million.		Classification.[b]
More than—	Not more than—		More than—	Not more than—	
.....	90	Good.	.....	150	Good.
90	200	Fair.	150	250	Fair.
200	430	Poor.	250	400	Bad.
430	.....	Bad.	400	.....	Very bad.

[a] Am. Ry. Eng. and Maintenance of Way Assoc. Proc., vol. 5, p. 595, 1904.
[b] Idem, vol. 9, p. 134, 1908.

The classification by incrusting and corroding constituents has been applied to the computations of scale-forming ingredients (s) in the analytical tables accompanying this report. The quantity of foaming ingredients (f) should always be considered in conjunction with the probable amount of scale or sludge that would be formed, the hardness of the scale, and the tendency toward corrosion. These ratings result in a classification rather more rigid than that usually reported by chemists of railroads in California, and for that reason those who are thoroughly familiar with local conditions and with the chemistry of water will doubtless prefer to disregard the descriptive terms of the classification and to draw their own conclusions regarding the quality of the waters from the figures representing scaling, foaming, and corrosion. The classifications are given principally for the aid of those not thoroughly familiar with such matters, and rather to indicate the limits of usefulness than to define rigidly the value of the waters.

No matter how low a water may be in undersirable constituents it is poor economy to use it if it is much poorer in quality than the average water of the region in which it occurs. On the other hand,

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if the best available supply is poor the economy of purifying it even at large expense is obvious. Along the Atlantic Coast, where waters containing less than 100 parts per million of incrusting ingredients are extremely common, a supply carrying 200 parts of such substances would not be considered fair for boiler use. Throughout most of Mississippi Valley, however, such a supply would be considered good, because in that region natural waters not exceeding 100 parts in scale-forming constituents are rare. This variance in local standards is well illustrated by the opinions on the two sides of San Joaquin Valley as to what constitutes a good boiler water, and because of it numerical standards should be interpreted relatively not literally. At the same time any classification by nominal ratings must be applied absolutely if the terms are to have comparative significance outside the region where the waters exist. Waters of poor quality can be improved by treatment in softening plants. How bad a water may be used without treatment depends on the cost of softening the water and the relative saving effected by the use of the softened water. A report[1] of the committee on water service of the American Railway Engineering and Maintenance of Way Association sets forth the factors involved. The benefits include the saving in boiler cleaning, repairs, and fuel, the decrease in the time during which the boilers must be withdrawn from service for cleaning and repairs, the decreased depreciation of the boilers, and the value of the materials removed by softening. The cost of softening includes the cost of labor and power for the softening apparatus, the cost of softening chemicals, the interest on the cost of installation, depreciation in the value of the softening plant, and the waste in changing boiler feed due to increased foaming tendency.

In locomotive service, it is in general economical to treat waters containing 250 to 850 parts per million of incrustants and to treat those containing less than 250 parts if the scale formed contains much sulphate.[2] As the incrusting solids may commonly be reduced to 80 or 90 parts per million, the economy of treating boiler waters deserves consideration in a region where many supplies contain 300 to 500 parts per million of incrusting matter.

The amount of mineral matter that makes a water unfit for boiler use depends on the combined effect in boilers of the softening reagents used with such waters and of the constituents not removed by softening. Sodium salts added to remove incrustants or to prevent corrosion increase the foaming tendency, and this increase may be great enough to render a water useless for steaming. It is not of much benefit to soften a water containing more than 850 parts per million of nonincrusting material and much incrusting sulphate.[3] Trouble

[1] Am. Ry. Eng. and Maintenance of Way Assoc. Proc., vol. 8, p. 601, 1907.
[2] Idem, vol. 6, p. 610, 1905.

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from priming in locomotive boilers begins at a concentration of about 1,700 parts per million of foaming constituents, and the limit of safety for stationary boilers is reached at a concentration of about 7,000 parts. Though waters containing as high as 1,700 parts per million of foaming constituents have been used, it is usually more economical to incur considerable expense in replacing such supplies by better ones.

WATER FOR MISCELLANEOUS INDUSTRIAL USES.

GENERAL REQUISITES.

Many articles are affected by the ingredients of the water used in their manufacture and can be improved by its purification. If by the same process the boiler efficiency of the factory can be increased the expense is often justified when it would not be warranted merely by the increased value of the product. This observation applies particularly to paper, pulp, and strawboard mills, laundries, and other establishments where large quantities of water are evaporated to furnish steam for drying, and to ice factories and similar plants where distilled water is required.

Besides its use for steam making water plays a specific part in many manufacturing processes. In paper mills, strawboard mills, bleacheries, dye works, canning factories, pickle factories, creameries, slaughterhouses, packing houses, nitroglycerin factories, distilleries, breweries, woolen mills, starch works, sugar works, canneries, glue factories, soap factories, and chemical works water becomes a part of the product or is essential in its manufacture. In most of these establishments the principal function of the water is that of a cleansing agent or a vehicle for other substances, and therefore a supply free from color, odor, suspended matter, microscopic organisms, and especially from bacteria of fecal origin, and fairly low in dissolved substances, especially iron, is with few exceptions satisfactory. But water hygienically acceptable is necessary where it comes into contact with or forms part of food materials, as in the making of beverages, sugar, and dairy or meat products. As ideal waters for any use are rare, the manufacturer must ascertain what degree of freedom from impurities is necessary to prevent injury to his machinery or to his output and whether the cost of obtaining such purity is counterbalanced by decreased cost of production and increased value of product.

EFFECTS OF DISSOLVED AND SUSPENDED MATERIALS.

The effects in some industries of the substances most commonly found in water are outlined in the following pages, the object being to offer approximate standards for classification.

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FREE ACIDS.

Free mineral acids, such as the sulphuric acid in drainage from coal mines or the hydrochloric acid in the effluents of some industrial establishments, are especially injurious and nearly always have to be neutralized before the waters containing them can be used industrially. In paper mills, cotton mills, bleacheries, and dye works waters containing a measurable amount of free mineral acid decompose chemicals, streak and rot fabrics, and corrode and rapidly destroy metal screens, strainers, and pipes.

SUSPENDED MATTER.

Suspended matter in surface waters may be of vegetable, mineral, or animal origin, as it consists of particles of sewage, bits of leaves, sticks and sawdust, and sand and clay. The fine silt so common in rivers of the West is largely derived from clay. Few well waters contain suspended animal or vegetable matter, but many carry finely divided sand and clay, and many become turbid by precipitation of dissolved ingredients. Suspended matter is objectionable in all processes in which water is used for washing or comes into contact with food materials, because it is likely to stain or spot the product. Suspended matter due to precipitated iron is especially injurious even in small amount. Suspended vegetable or animal matter liable to decomposition or to partial solution is much more objectionable, even in small amount (10 to 20 parts per million), than equal quantities of mineral matter. For these reasons water should be freed from suspended matter before being used for laundering, bleaching, wool scouring, paper making, dyeing, starch and sugar making, brewing, distilling, and similar processes. In making the coarser grades of paper, such as strawboard, a small amount of suspended matter is not especially injurious, but for the finer white and colored varieties clear water is essential.

COLOR.

Color in water is due principally to solution of vegetable matter. Materials bleached, washed, or dyed light shades in colored water are likely to become tinged. Highly colored waters can be used in making wrapping or dark-tinted papers but not in making the white grades, and paper manufacturers are put to great expense for water purification on that account. The lower waters are in color, therefore, the more desirable they are for use in bleacheries, dye works, paper mills, and other factories where brown tints in the products are undesirable.

IRON.

Iron is the most undesirable dissolved constituent, and its presence in comparatively small quantities necessitates purification. Many ground waters contain 1 to 20 parts per million of iron, which may

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be precipitated by exposure to the air and by release of hydrostatic pressure, causing the waters to become turbid, and many such waters develop rusty-looking gelatinous growths that may interfere in industrial operations. In all cleansing processes, especially if soap or alkali is used, precipitated iron is likely to cause rusty or dull spots. In contact with materials containing tannin compounds iron forms greenish or black substances that discolor the product. Therefore many waters containing amounts even as small as 1 or 2 parts per million of iron have to be purified before they can be used industrially. In water for dye works iron is especially objectionable and commonly prevents the use of the water without purification.[1] Iron in the water supply of paper mills may be precipitated on the pulp, giving a brown color, or during sizing or tinting, giving spotty effects. Water containing much iron can not be used in bleaching fabrics because salts that spot the goods are formed. The dark-colored compounds that iron forms with tannin discolor hides in tanning and barley in malting, and give beer a bad color, odor, and taste.[2]

CALCIUM AND MAGNESIUM.

Calcium and magnesium are similar in their industrial effects. In water their amounts bear a more or less definite relation to each other, most waters carrying 10 to 50 per cent as much magnesium as calcium. Both are precipitated on whatever is boiled in water containing them, forming a deposit that may interfere with later operations. They also decompose equivalent amounts of many chemicals employed in technical operations, causing waste and forming alkaline-earth compounds that interfere with the later treatment of fabrics. These are the strongest incentives to preliminary softening. Some of the chemicals used to disintegrate the fibers in making pulp are consumed by the calcium and magnesium in the water supply, though the loss from this source is not nearly so great as that which occurs later when the resin soap used in sizing the paper is decomposed by the calcium and magnesium. The insoluble soaps thus created do not fix themselves on the fibers, but form clots and streaks. Similar decomposition of valuable cleansing materials and subsequent deposition of insoluble compounds take place in laundering, wool scouring, and similar processes. In the manufacture of soap, calcium and magnesium form with the fatty acids curdy precipitates that are insoluble in water and therefore have no cleansing value. They interfere with many dyeing operations, neutralizing chemicals and changing the reactions of the baths, besides forming insoluble compounds with many dyes. Highly calcareous waters can not be used for boiling the grain in distilleries because they hinder proper action by causing the deposition of

[1] Sadtler, S. P., A handbook of industrial organic chemistry, p. 483, Philadelphia, 1900.
[2] De la Coux, M. A. J., L'eau dans l'industrie, pp. 187, 232, Paris, 1900.

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alkaline-earth salts on the particles of grain, nor for diluting spirits because they cause turbidity.[1] Very soft water, on the other hand, is said to be undesirable in paper mills for loading papers with any form of calcium sulphate because such waters dissolve part of the loading materials.[2] Probably waters high in chlorides would also be bad for this purpose, because chlorides increase the solubility of calcium sulphate.

CARBONATE.

The effects of carbonate and bicarbonate in waters used in industrial processes are commonly not differentiated. It is not unusual to estimate the combined carbonic acid and to state it as the carbonate without distinguishing between carbonate and bicarbonate, though in many natural waters the carbonate radicle is absent and the combined carbonic acid is in the form of bicarbonate. If hard waters proportionately high in carbonate and low in sulphate are boiled the bicarbonate radicle is decomposed, free carbonic acid is given off, and the greater part of the calcium and magnesium is precipitated. Consequently waters of that character are generally more desirable for industrial operations than waters high in sulphate and low in carbonate, whose hardening constituents are not greatly reduced by boiling. In beer making waters high in carbonate are said to produce dark-colored beers with a pronounced malt flavor because the carbonate increases the solubility of the nitrogenous bodies, whereas waters high in sulphate yield pale beers with a definite hop flavor because the sulphate reduces the solubility of the malt and the coloring matters.[3]

SULPHATE.

The influence of sulphate in beer making has been noted. Hard waters with sulphate predominating are desirable in tanning heavy hides, because they swell the skins, exposing more surface for the action of the tan liquors.[4] Sulphate interferes with crystallization in sugar making by increasing the amount of sugar retained in the mother liquor.

CHLORINE.

High chlorine is usually accompanied by high alkalies. Appreciable amounts of chlorine are injurious in many industrial processes. Beverages and food products, of course, can not be treated with waters very high in chlorine without becoming salty. In tanning, chlorides cause the hides to become thin and flabby.[4] Animal char-

[1] De la Coux, M. A. J., L'eau dans l'industrie, p. 251, Paris, 1900.

[2] Cross, C. F., and Bevan, E. J., A textbook of paper making, p. 294, New York, 1900.

[3] Brewing water, its defects and remedies, p. 19, American Burtonizing Co., New York, 1909. Also De la Coux, M. A. J., op. cit., p. 169.

[4] Parker, H. N., and others, The Potomac River basin: U. S. Geol. Survey Water-Supply Paper 192, p. 194, 1907.

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coal used in clarifying sugar is robbed of its bleaching power by absorption of salt. The quality of sugars is affected by chloride-bearing waters, because saline salts are incorporated in the crystals.[1] In the preparation of alcoholic beverages chlorides in large amount prevent the growth of the yeast and interfere with the germination of the grain. The only commercially developed way of removing chlorine from water is distillation. As the cost of this process has been greatly reduced by use of multiple-effect evaporators, it is worth consideration where chloride-bearing waters must be used.

ORGANIC MATTER.

Organic matter of fecal origin is, of course, dangerous in any water that comes into contact with food products, and water so polluted should be purified before being used. Care in this respect is particularly necessary in creameries, slaughterhouses, canneries, pickle factories, distilleries, breweries, and sugar factories. Organic matter not necessarily capable of producing disease is further undesirable in industrial supplies because it induces decomposition in other organic materials, like cloth, yarn, sugar, starch, meat, or paper, rotting and discoloring them, and because it causes slime spots on fabrics by supporting algæ growths.

HYDROGEN SULPHIDE.

Hydrogen sulphide (H_2S), a gas with an odor like that of rotten eggs, occurs dissolved in some ground waters. It is corrosive even in small quantities, and it also injures materials by discoloring and rotting them.

MISCELLANEOUS SUBSTANCES.

Silica and aluminum are usually not present in sufficient quantity appreciably to affect any industrial process, except those in which water is evaporated. Large quantities of sodium and potassium, by adding to the amount of dissolved matter, are objectionable in some manufacturing operations. Phosphates, nitrates, and some other substances not noted in this outline interfere with industrial chemical reactions, but they are present in few natural waters in sufficient quantity to have noticeable effect.

WATER FOR DOMESTIC USE.

PHYSICAL QUALITIES.

Entirely acceptable domestic supplies are free from suspended matter, color, odor, and taste and are fairly cool when they reach the consumer. The more nearly waters fulfill these conditions the more satisfactory they are for general use. Suspended mineral matter clogs pipes, valves, and faucets, and growths of microscopic plants

[1] De la Coux, M. A. J., op. cit., p. 152.

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suspended in water frequently cause odors and stains. The outlets of some artesian wells in San Joaquin Valley are surrounded by growths of microscopic organisms, which form tufts or layers in pipes and well casings and sometimes clog them. Detached particles escape through faucets, giving the water an unsightly appearance and staining clothes washed in it. So far as known, such growths in tanks and mains do not cause disease, but they often impart unpleasant odors that make the water objectionable. True color is usually due to dissolved vegetable matter and causes serious objection only when it exceeds 20 to 30 parts per million.

In general, the well waters of this area are satisfactory in respect to suspended mineral matter and color. Finely divided material from quicksands enters some driven wells, but such trouble is not so serious as it is in other parts of the country. A few waters, especially those containing iron, develop a turbidity of 10 to 30 parts per million on exposure to the air by precipitating dissolved matter, and such condition gives rise to apparent though not to real color. The only ground waters possessing much real color were found near the north end of Tulare Lake, where buried peat beds of old swamps probably contribute the organic matter that causes the color.

The odor most commonly noticed in the ground waters of the valley is that of hydrogen sulphide, especially in the area where artesian wells yield notable quantities of natural gas. According to analyses quoted by Watts [1] the gas from wells at Stockton comprises about 25 per cent nitrogen, 12 per cent hydrogen, and 60 per cent hydrocarbon illuminants estimated as marsh gas (CH_4), and probably this composition represents the general character of the gas throughout the valley, though the proportions of the substances may differ locally. The content of hydrogen sulphide is doubtless very small, but minute quantities of it are sufficient to cause appreciable odor. This smell, nauseating to some people, can usually be removed by spraying or splashing the water.

BACTERIOLOGICAL QUALITIES.

Before a water is used for domestic purposes there should be reasonable certainty that it is free from disease-bearing organisms and that it can be guarded against all chances of infection. The disease germs most commonly carried by water are those of typhoid fever. The bacilli enter the supply from some spot infected by the discharges of a person sick with this disease, and, though comparatively short lived in water, they persist in fecal deposits and retain their power of infection for remarkable lengths of time. Consequently, water from lakes and streams draining from population centers or

[1] Watts, W. L., The gas and petroleum yielding formations of the central valley of California: California State Mining Bur. Bull. 3, p. 75, 1894.

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from irrigated fields should not be used for drinking without purification. Wells should be so located as to be guarded against the entrance of filth of any kind, either over the top or by infiltration. Pumps and piping in the system should also be protected. Water from a carefully cased well more than 20 or 30 feet deep is acceptable if the well is located at a reasonable distance from privies, cesspools, and other sources of pollution. Many open dug wells and pits constructed as reservoirs around the tops of casings are exposed to fecal contamination from above or through cracks in poorly built side walls. Care should be taken that the casings of deep wells do not become leaky near the surface of the ground so as to allow pollution to enter. As a matter of ordinary precaution the ground should be kept clean and water should not be allowed to become foul or stagnant near any well, no matter how deep. If shallow dug wells are necessary they should be constructed with water-tight walls extending as far as practicable into the well and also a short distance above ground. The floor or curbing should be water-tight, and pumps should be used in preference to buckets for raising the water. Every possible precaution should be taken to prevent feet scrapings and similar dirt from getting into the well. Ground water is not only less likely to become contaminated when protected from surface washings, air, and light, but it keeps better and is less likely to develop microscopic plants that give it an unpleasant taste.

CHEMICAL QUALITIES.

The amounts of dissolved substances permissible in a domestic supply depend much on their nature. No more than traces of barium, copper, zinc, or lead should be present, because these substances are poisonous; however, their occurrence in measurable amounts in ordinary waters is so rare that tests for them are not usually made. Any constituent present in sufficient amount to be clearly perceptible to the taste is objectionable. Water containing 2 parts per million of iron is unpalatable to many people and may cause trouble by discoloring washbowls and tubs and by producing rusty stains on clothes. Tea and coffee can not be made satisfactorily with water containing much iron because a black inky compound is formed. Four or five parts of hydrogen sulphide makes a water unpleasant to the taste, and this gas is objectionable also because it corrodes well strainers and other metal fittings. The amounts of silica and aluminum ordinarily present in well waters have no special significance in relation to domestic supply.

Approximately 250 parts of chlorine makes a water "salty," and less than that amount causes corrosion. Where the chlorine content runs as low as 5 or 10 parts in normal waters unaffected by animal pollution the amount of chlorine is frequently taken as a

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measure of contamination. But the establishment of isochlors, or lines of equal chlorine, in San Joaquin Valley would be of little sanitary value, because many of the ground waters dissolve so much chlorine from the silt that the small changes caused by animal pollution are completely masked.

Calcium and magnesium are the chief causes of what is known as the hardness of water. This undesirable quality is indicated by increased soap consumption and by deposition on kettles of scale composed almost entirely of calcium, magnesium, carbonate, and sulphate. Calcium and magnesium, forming with soap insoluble curdy compounds that have no cleansing value, prevent the formation of a lather until these two basic radicles have been precipitated. Hardness is commonly measured by the soap-consuming capacity of a water expressed as an equivalent of calcium carbonate ($CaCO_3$), and it can be determined by actual testing with a standard solution of soap or can be computed from the amounts of calcium (Ca) and magnesium (Mg) by means of the following formula:

$$\text{Total hardness as } CaCO_3 = 2.5\ Ca + 4.1\ Mg.$$

If, as Whipple states,[1] 1 pound of ordinary soap would soften only about 24 gallons of water having a total hardness of 200 parts per million, it can readily be seen that the hardness of water is of intimate concern, especially in the west side, where waters as hard as 300 to 1,000 parts are common. Soda ash (sodium carbonate) is used to "break" or soften hard water in order to save soap. Some large cities in other States have found it advisable to soften their public supplies instead of leaving that task to the individual consumer.

MINERAL MATTER AND POTABILITY.

The lower waters are in mineral content the more acceptable they are as sources of supply, yet the amount of dissolved substances that can be tolerated in drinking water is much greater than that allowable in city supplies, for which hardness, corrosion, pipe clogging, and general utility have to be considered. Though there are certain limits above which the common ingredients are intolerable, these limits are not only difficult to ascertain but are also likely to shift. A normal water is not a pure solution of one salt, whose physiologic effect can be measured, but an indeterminate mixture of solutions of several salts whose effects are not easily differentiated. Further, though all animals select for drinking waters that are lowest in solids and avoid those that are highest, the same animals, when transported to districts of poor water, accustom themselves to supplies of far greater mineral content than those which before they would not

[1] Whipple, G. C., The value of pure water, p. 26, New York, 1907.

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touch. Consequently any general limits that may be assigned to the various mineral ingredients must be regarded as extremely flexible. The truth of this statement may be more fully appreciated by consideration of the data in Table 12, in which the analyses are grouped according to the chemical character of the waters and are arranged in each group in descending order of strength.

TABLE 12.—*Mineral matter in certain waters.*

[Parts per million.]

No.	Carbonate radicle (CO_3).	Sulphate radicle (SO_4).	Chlorine (Cl).	Total hardness as $CaCO_3$.	Total solids.	Calcium and magnesium (Ca+Mg).	Sodium and potassium (Na+K).	Character of water.
1....	43	Tr.	4,310	2,800	7,489	966	1,550	Na-Cl.
2[a]...	360	1,560	1,300	.....	5,000	.....	.....	Do.
3....	75	5	1,740	910	3,600	300	830	Do.
4....	46	328	1,520	506	3,600	170	1,030	Do.
5....	54	390	1,060	490	2,800	160	750	Do.
6....	200	5	279	31	872	11	320	Do.
7[a]...	110	2,300	800	.....	4,900	.....	.....	Na-SO_4.
8....	100	1,810	160	1,130	3,200	380	580	Do.
9....	362	1,640	460	1,760	4,100	150	600	Do.
10....	97	800	150	560	1,700	190	320	Do
11....	73	430	75	83	940	25	300	Do.
12[a]...	410	620	500	.....	2,470	.....	.....	Na-CO_3.
13....	963	Tr.	492	660	2,452	191	750	Do.
14....	208	Tr.	135	47	750	15	240	Do.
15....	100	Tr.	64	71	350	24	86	Do.
16....	75	1,680	145	1,280	2,900	400	400	Ca-SO_4.
17....	72	1,380	150	1,320	2,500	440	220	Do.
18....	60	1,380	135	1,100	2,400	370	305	Do.
19....	74	895	85	720	1,700	228	208	Do.
20....	38	9	4	50	169	16	16	Ca-CO_3.

[a] From a manuscript report by Herman Stabler on the underground waters of Carson Sink, 1904. The other analyses were made for this report.

The first group in Table 12 represents sodium chloride waters; that is, waters in which alkalies and chlorides predominate. Analysis No. 1, of water from a gas well in Stockton, represents a solution of the chlorides of calcium, magnesium, sodium, and potassium with little else. The water contains 4,310 parts per million of chlorine, and it is so salty that it is nauseating. The water represented by the next analysis has been used by the owner's family several years for all domestic purposes, but visitors object to it and consider it disagreeable to drink. No. 3 is the analysis of water from a deep well near Stockton that was formerly used as a source of domestic supply but has been abandoned. Nos. 4 and 5 are analyses of water from artesian wells near San Joaquin River, and though both supplies taste disagreeably salty to persons not accustomed to them, they are regularly used for drinking, cooking, and washing. Two gallons of the former water contains about as much common salt as a pound of uncooked ham. No. 6, the test of the supply of a very deep artesian well on the west side not far from Lemoore, indicates a water much lower in chloride but higher in carbonate or "black alkali." As the farm on which the well is situated was not occupied informa-

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tion regarding the value of the water as a constant beverage could not be obtained. It contains much gas and would be distasteful on that account; otherwise, however, it differs from that represented by No. 14 only in being somewhat higher in chloride and alkalies.

More strongly mineralized alkaline sulphate waters are drunk. The first one (see analysis No. 7), from a well in Carson Sink, was used when necessary, but the domestic supply was commonly hauled from another source several miles away. The water represented by analysis No. 8, which has been used for all domestic purposes for several years on a ranch west of Mendota, carries 1,800 parts of sulphate and exceeds 3,000 in total solids. It has a distinct taste and drinking a quart of it would be equivalent to taking somewhat less than a minimum dose of Glauber's salt. The water corresponding to No. 9 was used in the cook wagon and for watering the stock about one year on a ranch near Tulare Lake, but it was considered "alkali" water, and the domestic supply is now obtained from a deeper and much better well. Chloride and carbonate, as well as sulphate, however, are notably high in this water. The waters corresponding to 10 and 11 are used for all domestic purposes, though they have a distinct taste. The former is one of a battery of wells that have been the exclusive supply of a family for three years, and the latter is the municipal supply of Mendota.

The examples in the next group prove that less alkaline carbonates can be tolerated. The first analysis (No. 12) shows a water also high in chloride but not excessive in sulphate. This water has a color of 130, and it obviously carries much "black alkali." A party of men accustomed to alkali was so badly afflicted with diarrhea after drinking this water that work had to be stopped until another supply could be obtained. No. 13 shows nearly double the amount of carbonate but no sulphate. This water supplies a trough for stock, but it was evidently repugnant to the cattle, and current report in the neighborhood is to the effect that water from wells of the same depth "kills hogs," a phrase that seems to express the acme of undesirability. The mixture of alkaline carbonates and chlorides with the former predominating, indicated by test No. 14, has been used many years, but it is much lower in carbonate than the preceding two. The water listed under No. 15, the city supply of Stockton for many years, is drunk both by the inhabitants of the city and by visitors without harmful effect.

Though the next four are designated calcium sulphate waters the alkalies also are high, and, furthermore, application of the term calcium necessarily implies the presence of magnesium in amounts ranging from 10 to 40 per cent of the total calcium and magnesium given in the seventh column of the table. The water corresponding to No. 16 can not be used for cooking, and herders object to it so strongly

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that the drinking supply is hauled 8 miles from the well represented by No. 17, which carries 300 parts less of sulphate and about half as much sodium and potassium. Analysis No. 18, which is similar to No. 17, is of a water that has been used more than 10 years for cooking and drinking by one man. These three waters tasted unpleasantly strong to the writer and seemed to increase thirst instead of quenching it. Though the water represented by analysis No. 19 is lower in sulphate than the preceding ones of this group, it is strongly mineralized. It is the hotel supply at Huron, where it is used for all purposes.

Calcium carbonate waters are extremely common, but it is unusual for them to be so highly mineralized as those of other classes. The representative of this type, indicated by test No. 20, is low in total solids and is entirely acceptable for drinking and cooking.

The immediate consequence of drinking waters too high in mineral content is usually diarrhea. Many persons at first afflicted with this trouble become accustomed to the new supply and acquire what may be termed immunity. Whether other disorders result from the continued drinking of such waters is not known; and it is equally uncertain whether cattle and horses that so commonly are reported to have been killed by drinking strong mineral water were killed by the purging produced by the mineral matter in the water or by excessive consumption of water itself. It would appear from the data in Table 12 and the comments on it that alkaline carbonates are most injurious and alkaline sulphates least injurious and that alkaline chlorides occupy an intermediate position. This arrangement corresponds to the order of the same substances in reference to their toxic effect on plants. The most striking feature is that the amounts of mineral matter in most of these waters is much greater than that ordinarily considered permissible in drinking water. Waters exceeding 300 parts per million of carbonate, 1,500 parts of chloride, or 2,000 parts of sulphate are apparently intolerable to most people. These limits fortunately are far beyond the points where the substances in solution are clearly perceptible to the ordinary taste. In conclusion it can not be too emphatically stated that the information on this subject is fragmentary and uncertain and that any limits of mineral tolerance are modified by individual idiosyncrasy.[1]

INTERPRETATION OF FIELD ASSAYS IN RELATION TO POTABILITY.

CHEMICAL CHARACTER.

The total amount of mineral matter and the nature of the chief constituents in a water comprise the essential information for judging its potability in respect to mineral ingredients. Though nitrates,

[1] For further data see Dole, R. B., Concentration of mineral water in relation to therapeutic activity: U. S. Geol. Survey Mineral Resources, 1911, pt. 2, pp. 1175–1192, 1912.

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phosphates, sulphides, and other substances occur in some waters they may usually be disregarded in interpretation or their insignificance verified by a few laboratory analyses. Silica is usually present in colloidal form and it is relatively constant in quantity.

Calcium and magnesium are similar in many effects and they vary in amount together, calcium usually being the greater. Sodium and potassium are so similar in effect that they are seldom separated in industrial analyses but are reported together as sodium. Carbonate and bicarbonate, representing more or less conventionally different conditions of carbonate in equilibrium, may be considered together under the common term of carbonate (CO_3), to which bicarbonate is translated by dividing by 2.03. These groupings, rendered possible by the usual mode of occurrence of these substances and by their effects, greatly simplify classification of waters that have been assayed. Direct estimates are made of carbonate, sulphate, and chloride, the three principal acid radicles. The approximate amount of the alkaline earths, calcium and magnesium, can be computed from the total hardness; theoretically the total amount of these two bases must be between 40 per cent and 24 per cent of the total hardness expressed as $CaCO_3$; it usually lies between 37 per cent and 30 per cent, as the ratio of calcium to magnesium ranges from 7 to 1; therefore, one-third of the hardness is a reasonable estimate of the alkaline earths that will usually be in error less than 10 per cent. The alkalies, sodium and potassium, can be computed by the Stabler formula already noted (p. 57). These estimates and computations of the amounts of the chief acids and bases can then be used in applying the following classification:

Classification of water by chemical character.

Calcium (Ca) / Sodium (Na)	Carbonate (CO_3).
	Sulphate (SO_4).
	Chloride (Cl).

The designation "calcium" indicates that calcium and magnesium predominate, and "sodium" that sodium and potassium predominate among the bases; the designation "carbonate," "sulphate," or "chloride" shows which acid radicle predominates. Combination of the two terms classifies the water by type, and tabulation of the classification can be abbreviated by use of the symbols. The appellation $Na–CO_3$, for example, indicates that sodium and potassium predominate among the bases and that carbonate or bicarbonate, or both, predominate among the acids, and that the water would yield on concentration and crystallization more sodium carbonate than any other salt, though this classification does not in any way show the amounts of the salts in solution.

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The numerical preponderance of certain acid and basic radicles establishes the nature of many waters, but if further refinement in classification is desired comparison can be made of the reacting values of the radicles, which are the fundamental bases of the effect of the radicles. These values can be computed by multiplying the amount of each constituent by its valence and dividing the product by its molecular weight. The factors given in Table 13 can be used for that purpose. The factor for sodium may be used for the combined values of sodium and potassium. The reacting value of calcium and magnesium is nearly one-fiftieth of total hardness (H), as theoretically $H = 2.5\ Ca + 4.1\ Mg$, whence $\frac{H}{50} = 0.050\ Ca + 0.082\ Mg$.

TABLE 13.—*Factors for computing reacting values.*

Basic radicles.	Factor.	Acid radicles.	Factor.
Calcium (Ca)	0.0499	Carbonate radicle (CO_3)	0.0333
Magnesium (Mg)	.0821	Bicarbonate radicle (HCO_3)	.0164
Sodium (Na)	.0434	Sulphate radicle (SO_4)	.0208
Potassium (K)	.0255	Nitrate radicle (NO_3)	.0161
		Chlorine (Cl)	.0282

TOTAL SOLIDS.

Total solids can be computed from the data of a field assay in several ways, one of which is to calculate the probable amount of saline residue that would be produced by the acid radicles and to add thereto an arbitrary amount for silica, undetermined substances, and volatile matter. As potassium has the smallest reacting weight of the four common bases the assumptions that equal amounts of sodium and potassium are present and that calcium and magnesium are absent constitute an extreme condition representing a maximum saline residue; similarly, the assumptions that equal parts of calcium and magnesium are present and that the alkalies are absent constitute the condition representing a minimum saline residue. A formula based on an average between these two extremes gives an estimate of total solids (T. S.) within 15 per cent of the exact value for most natural waters.

$$T.\ S. = SiO_2 + 1.73\ CO_3 + 0.86\ HCO_3 + 1.48\ SO_4 + 1.62\ Cl.$$

The average content of silica (SiO_2) in most ground waters of San Joaquin Valley, according to available analyses, is about 30 parts per million in waters exceeding 400 parts of total solids and 50 parts in other waters. The estimate of solids should not be expressed more

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closely than to the nearest 10 parts or with more than two significant figures, and it may be translated into words by the following rating:

TABLE 14.—*Rating of waters by total solids.*

Total solids (parts per million).		Classification.
More than—	Not more than—	
.....	150	Low.
150	500	Moderate.
500	2,000	High.
2,000	.....	Very high.

PURIFICATION OF WATER.

GENERAL REQUIREMENTS.

Purification of water is removal or reduction in amount of the substances that render waters in their raw state unsuitable for use. It is practiced on a large scale with one or more of three objects in view: First, to render the supply safe and unobjectionable for drinking; second, to reduce the amount of the mineral ingredients injurious to boilers; third, to remove substances injurious to machinery or to industrial products. The largest purification plants in this country have been constructed almost solely to render the waters potable; and some waters, when so purified, need no further treatment to make them suitable for steaming and for general industrial use. But many other waters are hard, and increased appreciation of the value of good water has resulted in demand for the removal of the hardening constituents also.

Only a few settlements in San Joaquin Valley have surface water supplies for domestic use, and extensive installation of filter plants is doubtful. But if municipalities in the region ever adopt river supplies, filtration will be necessary because of the widespread pollution of the streams by drainage from irrigated lands. The present general use of boiler compounds, however, even on the east side, indicates the advisability of water softening. Feed-water purification plants are now common on the west side, and future development of that region of highly mineralized waters will be accompanied by increase in the number of these plants.

Removal of bacteria, especially those causing disease, and removal of turbidity, odor, taste, and iron are the principal requirements in purification of a municipal supply, elimination of bacteria and suspended matter being the most important. The common methods of effecting such purification are slow filtration through sand and rapid filtration after coagulation, both methods usually being com-

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bined with sedimentation.[1] The first process is known as "slow sand" filtration and the second as "mechanical" or "rapid sand" filtration. The efficiency of such filters is measured primarily by the ratio between the number of bacteria in the applied water and the number in the effluent. This figure, stated in percentage of removal, should be as high as 98, and it often reaches 99.8 per cent under normal conditions with a carefully operated filter of either kind.

Removal of scale-forming and neutralization of corrosive constituents are the chief aims in preparing water for steam making. For this two general methods are employed—cold chemical precipitation followed by sedimentation, and heating with or without chemicals, usually followed by rapid filtration. The first process is carried on in cold-water softening plants and the second in feed-water heaters.

METHODS OF PURIFICATION.

The requirements of the water supplies for industries are so varied that classification of purification methods is difficult. Water properly prepared for domestic and boiler use is suitable for most industrial establishments, and it is more economical for small manufacturers in large cities to obtain such water from the city mains than to maintain private supplies and purification apparatus. It is usually cheaper, however, for large factories to be supplied from separate sources, not only because of saving in actual cost of water but also because of the opportunity thus afforded of procuring water specially adapted to the needs of the factory. The common methods of industrial-water purification are those already mentioned, or combinations of them, modified to meet particular needs. In a few industrial processes, notably the manufacture of ice by the can system, water practically free from all dissolved and suspended substances is necessary and distilled water must be manufactured. Recent improvements in multiple-effect evaporators have greatly reduced the cost of distillation, so that it is now economical to distill for industrial and domestic use many waters heretofore considered too highly mineralized to be treatable. Many large factories, hotels, and even municipalities have installed multiple-effect stills.

Besides the four common systems of purification, many minor processes are used, sometimes alone, but more frequently as adjuncts to filters or softeners. Surface waters are screened through wooden or iron grids or through revolving wire screens to remove sticks and leaves before other treatment. Coarse suspended matter can be removed by rapid filtration through ground quartz or similar material, in units of convenient size, provided with arrangements for wash-

[1] For description of filters see Johnson, G. A., The purification of public water supplies: U. S. Geol. Survey Water-Supply Paper 315, 1913.

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ing the filtering medium similar to those used in mechanical filters. Very turbid river waters may be first allowed to stand in large sedimentation basins in order to reduce the cost of operating the filters by preliminary removal of a large part of the suspended solids. Supplies undesirable only because of their iron content are aerated by being sprayed into the air or by being allowed to trickle over rocks or by other methods that cause evaporation of carbonic acid and absorption of oxygen, thus precipitating and oxidizing the iron in solution so that it can readily be removed by rapid filtration. Similar aeration is employed to evaporate and oxidize dissolved gases that cause objectionable tastes and odors.

Disinfection by ozone, copper sulphate, calcium hypochlorite, and many other substances kills organisms that may cause disease or impart bad odors and tastes. Purification of this character must be done with substances that destroy the objectionable organisms without making the water poisonous to animals. Calcium hypochlorite, sodium hypochlorite, and chlorine gas are used to disinfect drinking water, and treatment with these substances is now widely practiced either as an adjunct to filtration or as an emergency precaution where otherwise untreated supplies are believed to be contaminated. Disinfection by this method is not a substitute for purification by filtration, for it does not remove suspended matter nor appreciable amounts of color, organic matter, swampy tastes, or odors, and it does not soften water.[1] Natural purification of water is accomplished largely through biologic processes,[2] in which the organic matter is oxidized by serving as food for bacteria and objectionable organisms are destroyed by the production of conditions unfavorable to their existence. Action of this kind takes place in reservoirs and lakes, and it is also relied upon in many processes for the artificial purification of sewage.[3]

SLOW SAND FILTRATION.

Slow sand filtration consists in causing water to pass downward through a layer of sand of such thickness and fineness that the requisite removal of suspended substances is accomplished. The slow sand filter is also called the "continuous" and the "English" filter. On the bottom of a water-tight basin, commonly constructed of concrete, perforated tiles or pipes laid in the form of a grid are covered with a foot of gravel graded in size from 25 to 3 millimeters in diameter from bottom to top. A layer of fine sand, 3 to 4 feet deep, is put over the gravel, which serves only to support the sand.

[1] Op. cit., p. 71.

[2] Hazen, Allen, Clean water and how to get it, p. 83, New York, 1907.

[3] Winslow, C.-E. A., and Phelps, E. B., Investigations on the purification of Boston sewage, with a history of the sewage-disposal problem: U. S. Geol. Survey Water-Supply Paper 185, 1906.

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When water is applied on the surface, it passes through the sand and the gravel and flows away through the underdrain. The suspended materials, including bacteria, are removed by the sand, the action of which is rendered more efficient by the rapid formation of a mat of finely divided sediment on its surface. When this film has become so thick that filtration is unduly retarded, the water is allowed to subside and about half an inch of sand is removed, after which filtration is resumed. The sand thus taken off is washed to free it from the collected impurities and is replaced on the beds after they have been reduced about a foot in thickness by successive scrapings. As cleaning necessitates temporary withdrawal of filters from service, they are divided into units of convenient size, usually one-half to 1 acre each, so that the operation of the entire system may not be interrupted. Most modern filters are roofed and sodded, as this facilitates cleaning by preventing the formation of ice, permits work on the filter beds in all kinds of weather, inhibits algæ growths, and prevents agitation of the water by wind and rain.

The foregoing are the essential features of a slow sand filter, but several adjuncts render this system more efficient. A clear-water basin for the filtered supply, covered to prevent deterioration of the water, is provided in order that the varying rate of consumption may not unduly affect the rate of filtration. Clarification of turbid water is rendered more economical by allowing it to stand for one to three days, during which a large portion of the suspended matter is deposited, so that the time between sand scrapings is lengthened. In some plants roughing or preliminary filters consisting of beds of coarse sand or fine crushed stone are provided, through which the water flows 15 to 20 times as fast as through the sand filters, a very large proportion of the suspended matter being thus removed. Objectionable odors and tastes may be obviated by aeration before or after filtration. Killing the bacteria before filtration by use of chlorine or other germicides is also practiced.

Slow sand filtration removes practically all the suspended matter and the bacteria. Color is only slightly reduced and hardness is not changed. The process is specially adapted to waters low in color and suspended matter and slightly polluted. Very small particles of clay are not removed by these filters and waters carrying such particles only for short periods may be benefited by the occasional addition of a coagulant before filtration. It can readily be seen that the efficiency of this kind of filter depends largely on the character of the sand, as the ability to prevent the passage of suspended matter is governed by the size of the spaces between the sand particles. The rate of filtration depends on the average size of the sand particles, the thickness of the sand bed, the head of water, and the turbidity. Under ordinary conditions of operation in the United

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States the rate of slow sand filtration of water previously subjected to sedimentation is 2,000,000 to 4,000,000 gallons per acre per day.

RAPID SAND FILTRATION.

The rapid sand filter is also known as the American filter, and until recently it was generally styled the "mechanical" filter, because of its contrivances for washing the sand. Its distinctive features are its use of a coagulant and its high rate of filtration. While the raw water is entering the sedimentation basin, which is smaller than that used with slow sand filters, it is treated with a definite proportion of some coagulant, which forms by its decomposition a gelatinous precipitate that unites and incloses the suspended material, including the bacteria, and absorbs the organic coloring matter. This combined action destroys color and makes suspended particles larger and therefore more readily removable. When aluminum sulphate, the coagulant most commonly used, is decomposed aluminum hydrate is precipitated and the sulphate radicle remains in solution, replacing an equivalent amount of the carbonate, bicarbonate, or hydrate radicle. One part per million of ordinary aluminum sulphate requires somewhat more than 0.6 part of alkalinity expressed as $CaCO_3$ to insure complete decomposition.[1] The natural alkalinity of many waters is sufficient to effect this reaction. If the alkalinity is not sufficient part of the aluminum sulphate remains in solution and good coagulation does not take place. Therefore lime or soda ash is added if the alkalinity is too low. The proper amount of aluminum sulphate to be used is determined by the amounts of color, organic matter, and suspended matter, and by the fineness of the suspended matter, and it is best ascertained by direct experimentation with the water to be purified. Much of the trouble in operating the earlier types of rapid filters has been caused by failure to produce a good "floc" or precipitation because of improper ratios of coagulant and alkalinity.

Ferrous sulphate instead of aluminum sulphate is used as a coagulant in some filtration plants. With this substance lime must be added in order to bring about proper coagulation.

The water, after having been mixed with the coagulant, is allowed to stand three or four hours in the sedimentation basin, where a large proportion of the suspended particles is deposited. It is then passed rapidly through beds of sand or ground stone to remove the rest of the suspended matter. Many filters now in use are built in cylindrical form 10 to 20 feet in diameter, and some are so designed that filtration can be hastened by pressure. The sand, 30 to 50 inches deep and coarser than that used in slow sand filters, rests on a metallic

[1] Hazen, Allen, Report of the filtration commission of the city of Pittsburgh, p. 57, 1899.

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floor containing perforations large enough to allow ready issue of the water, but small enough to prevent passage of sand grains. When the filter has become clogged the flow of water is reversed, filtered water being forced upward through the sand to wash it and to remove the impurities, which pass over the top of the filter with the wasted water. A revolving rake with long prongs projecting downward into the sand mixes it during washing and prevents it from becoming graded into spots of coarse or fine particles. In recently constructed works rectangular filters 300 to 1,300 square feet in area have been built, in which the sand is agitated during washing by compressed air forced through it at intervals instead of by a revolving rake. Larger orifices in the strainers are also being used, the passage of sand being prevented by fine gravel over the strainer pipes. The rate of filtration is from 100,000,000 to 120,000,000 gallons per acre per day. The time between washing is 6 to 12 hours, depending principally on the turbidity of the applied water.

Mechanical filtration removes practically all suspended matter, reduces the color to unobjectionable proportions, and under some conditions removes part of the dissolved iron. The permanent hardness of the water is increased in proportion to the amount of sulphate added by the coagulant, and if only enough lime to decompose the coagulant is added, the total hardness is slightly increased. If larger amounts of lime are added, however, the total hardness is reduced. If soda ash is used in place of lime the foaming constituents are slightly increased. The chemicals are always added in solution. As this method of filtration is used almost entirely for river waters with fluctuating contents of suspended and dissolved matter proper operation requires constant and intelligent attention.

COLD-WATER SOFTENING.

The principal objects of water softening are to remove the substances that cause incrustations in boilers, particularly calcium and magnesium, and to neutralize those that cause corrosion. Solutions of chemicals of known strength are added to the raw supply in such proportion as to precipitate all the dissolved constituents that can be economically removed by such treatment. The water is then allowed to stand long enough to permit the precipitate to settle, after which the clear effluent is drawn off; or the partly clarified effluent may be filtered very rapidly through thin beds of coke, sponge, excelsior, bagging, or similar material in order to remove particles that have not subsided in the tanks. The water softeners on the market differ from one another chiefly in the precipitant, in the filtering medium if one is used, and in the mechanism regulating the incorporation of the chemicals with the water. Installations may be of any size to suit consumption, and the process can

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CHEMICAL COMPOSITION OF THE SURFACE WATERS.

RIVERS.

During a study of the quality of the surface waters of California conducted by the Geological Survey in cooperation with the California Department of Engineering in 1906–1908 samples of water collected daily for a period of one year at selected stations on several rivers in San Joaquin Valley were united in sets of 7 or 10 consecutive samples as deemed advisable, and analyses were then made of the composites thus obtained. As the complete analyses have already been published [1] it is sufficient here to quote only the mean, maximum, and minimum conditions of chemical composition during the progress of the investigation. The analyses prior to March, 1906, were made by F. M. Eaton; for the remainder of that year they were made by P. L. McCreary; and during 1908 by Walton Van Winkle, who was assisted by W J McGee, William Reinhart, and W. C. Packard.

[1] Van Winkle, Walton, and Eaton, F. M., The quality of the surface waters of California: U. S. Geol. Survey Water-Supply Paper 237, 1910.

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TABLE 15.—*Quality of the river waters of San Joaquin Valley.*

[Parts per million except as otherwise designated.]

Source.	Condition.	Suspended matter.	Silica (SiO_2).	Iron (Fe).	Calcium (Ca).	Magnesium (Mg).	Sodium and potassium (Na+K).	Carbonate radicle (CO_3).	Bicarbonate radicle (HCO_3).	Sulphate radicle (SO_4).	Chlorine (Cl).	Total dissolved solids.	Total hardness as $CaCO_3$.[a]	Incrusting constituents.[a]	Foaming constituents.[a]	Alkali coefficient[a] (inches).
San Joaquin River near Lathrop, Jan. 1 to Dec. 31, 1906.	Maximum	264	19	0.10	41	16	68	0.0	123	60	92	358	169	167	184	20
	Minimum	4	10	.....	8.9	3.6	11	.0	30	8.7	8.8	60	37	42	30	150
	Mean	60	16	.23	18	8.0	27	.0	66	26	30	161	78	82	73	65
San Joaquin River near Lathrop, Dec. 31, 1907, to Dec. 31, 1908.	Maximum	193	25	.20	40	21	77	.0	139	73	116	416	186	178	208	18
	Minimum	15	12	.45	6.6	3.1	6.1	.0	22	19	4.0	52	29	37	16	400
	Mean	52	19	.30	20	10	36	.0	74	39	47	205	90	95	97	40
Mokelumne River at Clements, Jan. 1 to Dec. 31, 1906.	Maximum	504	25	.....	25	6.7	23	.0	84	24	19	126	91	110	62	90
	Minimum	28	11	.....	6.3	1.8	9.0	.0	17	5.8	3.9	30	23	33	24	130
	Mean	84	14	.18	12	3.8	13	.0	42	12	7.3	75	46	56	35	120
Stanislaus River at Knights Ferry, Jan. 1 to July 31, 1906.	Maximum	642	9.6	.....	23	7.4	15	.0	106	22	16	138	88	90	40	120
	Minimum	16	8.8	.....	7.1	3.5	8.2	.0	25	9.2	4.9	44	32	36	22	320
	Mean	140	14	.20	11	5.0	11	.0	46	11	5.6	83	48	54	30	150
Tuolumne River at Lagrange, Jan. 1 to Dec. 31, 1906.	Maximum	284	11	.10	18	6.4	13	.0	72	17	7.1	134	71	75	35	200
	Minimum	12	6.0	.....	8.7	2.0	9.3	.0	15	7.7	4.9	40	17	20	25	150
	Mean	68	11	.19	10	4.3	12	.0	41	12	6.6	74	43	48	32	140
Merced River at Merced Falls, Jan. 1 to July 31, 1906.	Maximum	260	24	.....	21	5.6	15	.0	77	19	9.4	116	95	95	40	180
	Minimum	6	15	.....	8.0	4.2	13	.0	17	7.3	3.9	40	37	46	35	80
	Mean	52	14	.10	9.1	3.8	9.3	.0	35	11	5.6	65	39	47	25	240
Kern River near Bakersfield, Jan. 1 to Dec. 12, 1906.	Maximum	1,836	22	.....	39	6.1	108	.0	110	71	14	270	123	147	291	90
	Minimum	14	12	.....	10	2.6	12	.0	30	9.4	4.4	56	36	46	32	100
	Mean	163	18	.15	18	4.2	22	.0	71	21	9.1	127	62	78	60	65

[a] Computed. Suspended matter has been disregarded in these computations in order that the results may be comparable with those calculated from analyses of ground waters.

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The extremes of suspended and dissolved solids that are indicated in Table 15 did not necessarily occur at the same time, but the amounts of the various dissolved constituents correspond to the reported dissolved solids. The waters of Mokelumne, Stanislaus, Tuolumne, and Merced rivers, which were sampled at or near the entrance of the streams into the valley and before they have been used for irrigation, are low in all constituents, and they compare favorably with the waters of rivers along the Atlantic Coast, which are considered entirely acceptable in respect to their mineral constituents. The water of Hudson River at Hudson, N. Y., though less changeable in quality, is distinctly higher than any of these in dissolved matter, and the water of Lake Superior, carrying 60 parts per million of dissolved matter, is only slightly lower in mineral content. Though the California stream waters fluctuate considerably in their load of mineral matter, they are no more highly mineralized at their worst than the best of the ground waters. They would be classed as moderately soft by the most critical standards; they are low in dissolved scaling and foaming constituents, and therefore sedimentation to remove the varying amounts of suspended matter is all that is required to make them good boiler waters. The computed alkali coefficients indicate that the waters even at the lowest stages are excellent for use in irrigation, and this classification is amply corroborated by experience. Kern River, sampled at the mouth of the canyon 5 miles northeast of Bakersfield, is somewhat higher in mineral content than the other streams, but still it is moderate. Such increase in the southern end of the valley is natural in view of the low rainfall, which has been insufficient to remove from the ground the accumulation of soluble salts.

The analyses of water from San Joaquin River at the Southern Pacific Co.'s bridge near Lathrop, a few miles above Stockton (San Joaquin Bridge), show how evaporation, seepage from irrigated tracts, and surface and subsurface drainage from the entire valley increase the mineral content of the outflowing water and tend to differentiate it from the mountain tributaries. Yet, even though the river water is subject to these adverse influences, it is acceptable for irrigation and for boiler use. It varies greatly in quality from season to season, being lowest in dissolved matter during the spring freshets and highest during the fall when the river is at its lowest stages.

TABLE 16.—*Mean discharge of certain tributaries of San Joaquin River compared with the mean mineral content of that stream during 1906 and 1908.*

	1906	1908
Mean suspended matter in the water of San Joaquin River near Lathrop (parts per million)	60	52
Mean dissolved matter in the water of San Joaquin River near Lathrop (parts per million)	161	205
Mean discharge in second-feet per square mile: [a]		
Stanislaus River at Knights Ferry	3.63	.837
Tuolumne River at Lagrange	3.33	.960
Merced River at Merced Falls	2.63	.631

[a] U. S. Geol. Survey Water-Supply Papers 213 and 251.

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The difference between the average quality of the water of San Joaquin River during different years is not very great, as the data in Table 16 indicate. The mean discharge of the three principal tributaries was approximately four times as great in 1906 as in 1908, but the amount of dissolved matter at San Joaquin Bridge was less than 30 per cent greater during the dry year, and the decrease of suspended matter corresponding to the decrease in discharge is only 13 per cent. In general suspended matter varies directly and dissolved matter inversely with the discharge of streams, but these relations are neither absolute nor invariable, and study of analyses of several other river waters has demonstrated that the fluctuation of the average content of mineral matter is not so great from year to year as the fluctuation in discharge.

TABLE 17.—*Comparison of the average condition of the water of San Joaquin River with the average condition of three tributaries in 1906.*

Constituents.	Parts per million.				Percentage of anhydrous residue.			
	Stanislaus River at Knights Ferry.	Tuolumne River at Lagrange.	Merced River at Merced Falls.	San Joaquin River near Lathrop.	Stanislaus River at Knights Ferry.	Tuolumne River at Lagrange.	Merced River at Merced Falls.	San Joaquin River near Lathrop.
Suspended matter	140	68	52	60	.....	.....	.....	.....
Dissolved solids	83	74	65	161	.....	.....	.....	.....
Total hardness [a]	48	43	39	78	.....	.....	.....	.....
Silica (SiO_2)	14	11	14	16	17.3	14.4	20.0	10.1
Iron (Fe)	.20	.19	.10	.23	.3	.2	.2	.1
Calcium (Ca)	11	10	9.1	18	13.6	13.1	13.0	11.4
Magnesium (Mg)	5.0	4.3	3.8	8.0	6.2	5.6	5.4	5.1
Sodium and potassium (Na+K)	11	12	9.3	27	13.6	15.8	13.3	17.1
Carbonate radicle (CO_3)	.0	.0	.0	.0	28.5	26.3	24.3	20.9
Bicarbonate radicle (HCO_3)	46	41	35	66	.....	.....	.....	.....
Sulphate radicle (SO_4)	11	12	11	26	13.6	15.8	15.8	16.4
Chlorine (Cl)	5.6	5.6	5.6	30	6.9	8.8	8.0	18.9

[a] Computed.

Comparison of the average condition of the San Joaquin for 1906 with the average condition of Stanislaus, Tuolumne, and Merced rivers, the three tributaries entering above San Joaquin Bridge, brings out the essential differences in the waters (Table 17). Though nearly all constituents are greater in quantity in the San Joaquin the principal change in chemical composition is increase of the percentages of sodium, potassium, and chlorine at the expense of carbonate; in other words, chlorides of the alkalies are added to the solution. The moderate increase in mineral constituents is less than what might be expected in view of the high mineral content of the west-side ground waters and the semiarid condition of the valley.

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TULARE LAKE.

The usually high mineral content of the water as well as the intermittent nature of Tulare Lake prevents its use for irrigation. As the landlocked basin forms an immense evaporating pan in a semiarid region the dissolved salts that are brought in by tributary streams have been deposited in the lake bed after the water has evaporated, the salts being partly redissolved later or left under or mixed with protective layers of silt. That such successive concentrations, dilutions, and depositions have taken place for many centuries is shown by the known history of the lake and by the highly mineralized condition of the first few hundred feet of silt underlying its bed.

When the area of the lake has been greatest the proportion of substances in solution has been low enough to permit use of the water for irrigation, but its usual unfitness is established by analyses made by chemists at the agricultural experiment station of the University of California under the direction of E. W. Hilgard. The results of their tests, given in Table 18, can not be reduced to ionic form because of the methods of analysis and they are therefore given in the original hypothetical combinations, the only change being that the amounts have been converted from grains per gallon to parts per million.

TABLE 18.—*Partial analyses of water from Tulare Lake.*[a]

[Parts per million.]

	Total residue.	Residue insoluble in water.	Organic and volatile matter.	Sodium carbonate.	Sodium chloride, sodium sulphate, etc.
A	1,445	230	38	478	648
B	1,403	92	91	604	616
C	1,401	128	76	521	676
D	1,399	.....	.....	.....	.....
E	1,400	143	39	478	740
F	3,504	63	241	1,272	.....
G	5,188	119	276	1,622	3,170
H	660	88	85	230	873
I	1,301	113	77	530	581

A. Near southeast corner of the lake inside of Root Island, 300 yards from shore.
B. Near middle of lake at surface.
C. Near middle of lake at depth of 10 feet.
D. Near middle of lake at depth of 20 feet. (The first four samples apparently were collected in the spring of 1880.)
E. Sample collected in January, 1880.
F. Sample collected in June, 1888.
G. Sample collected in February, 1889.
H. Near mouth of Kings River, March 28, 1880. Taken at surface when a strong wind brought in more river water than usual.
I. Near outlet of West Side Canal at depth of 10 feet. (Probably taken at same time as sample H.)

Samples A to E inclusive were collected in 1880 while the lake was decreasing in size and its dissolved salts were being concentrated. The samples collected at reasonable distance from the shore indicate that the lake throughout carried practically the same amounts of

[a] Compiled from California Univ. Agr. Exper. Sta., Rept. for 1890, appendix.

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dissolved matter. The water at that time was too high in mineral content to be suitable for use. Samples F and G, taken in 1888 and 1889 while the lake was low, show much greater concentration of the soluble substances, the total residue having become more than tripled in 1889. The results of these tests prove the futility of any project involving use of the lake waters for irrigation. If the supply were suitable during uncertain periods when the lake is large the inevitable concentration accompanying evaporation would make the water dangerous during low stages. Dilution of such strong water by mixing it with a supply from Kings River would result in reducing one excellent water to poor condition.

TABLE 19.—*Chemical composition of the water of Tulare Lake.*[a]

Constituents.	Parts per million.			Percentage of anhydrous residue.		
	1	2	3	1	2	3
Total solids	1,400	1,401	5,188			
Organic and volatile matter	39	76	276			
Silica (SiO_2)	8	12	32	0.59	0.92	0.65
Alumina (Al_2O_3)		5			.38	
Calcium (Ca)	20	17	14	1.47	1.31	.28
Magnesium (Mg)	24	21	13	1.76	1.62	.26
Sodium (Na)	458	460	1,760	33.60	35.38	35.83
Potassium (K)	25		120	1.83		2.44
Carbonate radicle (CO_3)				26.56	28.62	19.52
Bicarbonate radicle (HCO_3)	735	755	1,945			
Sulphate radicle (SO_4)	230	203	1,020	16.87	15.61	20.76
Chlorine (Cl)	236	210	994	17.32	16.16	20.26
Scale-forming ingredients (s)	107	102	95			
Foaming ingredients (f)	1,300	1,240	5,100			
Probability of corrosion (c)[b]	N. C.	N. C.	N. C.			
Alkali coefficient (inches)	2.2	2.2	.6			
				100.00	100.00	100.00

[a] Analyses made in the chemical laboratory of the Agricultural Experiment Station, University of California.

[b] N. C.=noncorrosive.

Table 19, giving the chemical composition of the lake water in parts per million and in percentage of the anhydrous residue, shows in more detail the nature and amounts of the dissolved substances. Analysis No. 1, corresponding to E in Table 18, gives the composition in January, 1880; No. 2 is apparently the same as C (Table 18), collected in the spring of 1880; and No. 3 shows the composition in February, 1889. The analyses, stated by Hilgard in hypothetical combinations, have been computed to ionic form and to parts per million by the writer. The water belongs to the sodium carbonate type, the proportion of alkaline earths being low. The percentage of calcium and magnesium decreased greatly between 1880 and 1889, a change compensated by a proportionate increase in alkalies. The relative amount of carbonate decreased appreciably, while sulphate and chloride correspondingly increased. This indicates the deposition of alkaline-earth carbonates. The alkali coefficients are so low

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that the water could not be considered suitable for irrigation. Though the amounts of scale-forming ingredients are low, and such waters would probably not corrode boilers, the contents of foaming constituents would render such supplies unfit for boiler service. Tulare Lake may be regarded as a catch basin whose water is valueless.

BUENA VISTA RESERVOIR.

Kern River has several delta channels spread fanlike in the valley west of Bakersfield, and some of these channels formerly conveyed the water of the river to a shallow depression comprising the basins of Kern and Buena Vista lakes and Buena Vista Swamp. In recent years, however, the original courses have been modified by levees and diversion canals until at present none of the flow reaches Kern Lake basin except intermittently through an irrigating ditch, and only the flow at high stages is directed toward Buena Vista reservoir. This body of water, occupying the former basin of Buena Vista Lake, in T. 31 S., R. 25 E., and T. 32 S., R. 25 E., is a storage reservoir for irrigation canals to the northwest. It is separated by a levee from the basin of Kern Lake, whose bed is now dry and under cultivation. The analysis of a sample from the east end of Buena Vista reservoir in the spring of 1896 is reported in Table 20.

TABLE 20.—*Partial analysis of water from Buena Vista reservoir.*[1]

[Parts per million.]

Total residue	503
Organic and volatile matter	100
Residue insoluble in water	111
Residue soluble in water	292
Soluble residue:	
Sodium sulphate	269
Sodium chloride	23
Sodium carbonate	0
Insoluble residue:	
Silica	53
Carbonates of calcium and magnesium and calcium sulphate	58

When the water is in the condition shown by these tests, or is more dilute, it is suitable for irrigation and for use in boilers. The water may be prevented from becoming too strong by continual replenishment from Kern River. Water from Kern Lake on March 24, 1880, before it dried up, contained more than 3,600 parts per million[2] of mineral matter and was bad for irrigation.

[1] Analysis performed in the laboratory of the California Agricultural Experiment Station under direction of E. H. Loughridge. California Univ. Agr. Exper. Sta. Rept. for 1895–1897, p. 77. Converted into parts per million by the writer.

[2] California Univ. Agr. Exper. Sta. Rept. for 1890, appendix, p. 48.

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DENUDATION AND DEPOSITION.

RATE OF DENUDATION IN THE SIERRA.

San Joaquin Valley has been filled by alluvium deposited by entering streams, but how much of the deposition took place in an arm of the ocean, how much in a fresh-water lake, and how much above water, and many other circumstances of the fluvial upbuilding are more or less conjectural. The rate at which material in the active basin of San Joaquin River—the portion east of the present river bed and north of Kings River—is now being moved has been calculated from the analyses quoted in Table 15 and gagings of the tributaries, and the results of these calculations are summarized in Table 21. During 1906 approximately 225 tons per square mile in the form of dissolved matter and 265 tons per square mile in the form of suspended matter were transported from the slopes of the Sierra Nevada into the valley.

TABLE 21.—*Rate of denudation on part of the western slope of the Sierra Nevada in 1906.*

Drainage basin.	Area.[a]	Mean run-off.[a]	Mineral content of water.		Denudation.	
			Average suspended matter.[b]	Average dissolved matter.[b]	Suspended matter.	Dissolved matter.
	Sq. mi.	*Sec.-ft. per sq. mi.*	*Parts per million.*	*Parts per million.*	*Tons per sq. mi. per year.*	*Tons per sq. mi. per year.*
Mokelumne River above Clements	642	3.04	84	75	232	224
Stanislaus River above Knights Ferry	935	3.63	140	83	472	296
Tuolumne River above La Grange	1,500	3.33	68	74	188	243
Merced River above Merced Falls	1,090	2.63	52	65	197	168
Weighted mean					265	225

[a] U. S. Geol. Survey Water-Supply Paper 213, 1907.
[b] U. S. Geol. Survey Water-Supply Paper 237, 1910.

The figures of denudation in tons of dissolved matter per square mile per year in Table 21 have been computed by multiplying together the mean run-off, the average dissolved matter, and the factor 0.985. Denudation as suspended matter can not be so well approximated by similar computation with averages because the amount of suspended matter carried during a heavy flood may be greater than that during all the rest of the year. Therefore, denudation as suspended matter has been computed for each 10-day period represented by the samples, and the sum of these estimates has been divided by the area of the basin to obtain the denudation in tons per square mile per year in the form of suspended matter. Thus the removal of material from 4,167 square miles of the Sierra has been estimated. If it is assumed that the denudation on the first three basins is typical of the north-

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ern two-thirds of the mountain slope and that that on Merced River basin is typical of the southern third, the weighted means for the 7,500 square miles of the Sierra tributary to San Joaquin Valley north of Kings River may be obtained. These two figures represent an annual movement of 1,700,000 tons of dissolved matter and 2,000,000 tons of suspended matter into the valley. This is equivalent to a denudation of 26 ten-thousandths of an inch annually, or 1 inch in 385 years, a high rate of denudation.

These estimates do not take into account the dissolved matter that is carried into the valley by the ground waters, but as the present problem is essentially one of silt movement this chemically dissolved matter can be neglected. No allowance has been made for the "bottom load," or material rolled along the beds of the streams, because the meager information in reference to this manner of transportation tends to show that the bottom load moved past a given point in a river that is not overloaded is a very small percentage of the total load. The sectional area of the heavy load near the bottom is only a small part of the total cross section through which suspended matter is transported, and the bottom load necessarily moves more slowly than the lower filaments of water, which in turn move more slowly than any other waters in the cross section. Therefore, though bottom material may be obvious because of the size of its particles, it probably constitutes only a small fraction by weight of the total material that is moved.

How long a period may be represented by estimates based on one year's studies is uncertain. According to the figures representing the mean discharge of several streams in the valley,[1] the run-off during 1906 was considerably higher than normal, and the estimates of transported silt may, therefore, be considered greater than the normal for the present century.

RATE OF DEPOSITION IN THE VALLEY.

As no measurements of the discharge of San Joaquin River near Lathrop were made during the period in which samples were collected, 1.00 second-foot per square mile has been taken as a reasonable estimate of the average run-off throughout the 16,500 square miles of the basin north of Tulare Lake. This figure and the averages of analyses at Lathrop for 1906 (Table 17) give the annual removal of material by San Joaquin River as 2,600,000 tons of dissolved and 1,000,000 tons of suspended matter. That is, about 1,000,000 tons more of suspended matter and 900,000 tons less of dissolved matter are brought into the valley annually by the active east-side tributaries of the San Joaquin than are carried to the bay. The excess

[1] Clapp, W. B., The surface water supply of California: U. S. Geol. Survey Water-Supply Paper 213, 1907.

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of dissolved matter undoubtedly is contributed by underflow. Though no perennial streams enter San Joaquin River from the west side above the sampling station at San Joaquin Bridge, some suspended and dissolved matter undoubtedly reaches the main stream over the surface during the rainy season. On the other hand, some of the suspended material brought into the valley by mountain streams is later disintegrated and dissolved and passes out in solution. These features slightly modify the estimates, some increasing and others decreasing the computed differences between outgoing and incoming material; due allowance for their influence, however, seems to be made by assuming that the difference between the amounts of outgoing and incoming silt represents the present annual accretion. This quantity, 1,000,000 tons, distributed evenly over the 3,500 square miles of plains region between San Joaquin River and the Sierra would represent an annual deposition of 285 tons per square mile. If this material, thoroughly dried and compacted by pressure, is assumed to weigh 100 pounds per cubic foot,[1] it would represent an annual upbuilding of 24 ten-thousandths of an inch, or 1 inch in about 420 years.

As wells in the valley have penetrated 2,000 to 2,500 feet of sediment, this annual accretion would indicate a period of not less than 6,000,000 years for the fluvial filling. It is, of course, absolutely a matter of speculation whether the present rate of deposition represents the average rate during the entire period in which the valley has been filled. Mr. Mendenhall states (p. 28) that "the wells drilled throughout the valley prove that the sediments underlying it are all fine," and this indicates that past rates of deposition could not have been much greater than the present rate, for if they had been the transported material would have been coarser and the particles of deeper sediments in the valley would now be larger than those of the upper sediments. But even under the extreme assumption that 4,000,000 tons, or twice the present amount, of silt had been brought annually into the valley and that none of it had been transported to the ocean, the time of filling would not be less than 1,500,000 years. This calculation, approximate and based on hypotheses though it may be, indicates that the time occupied by the valley filling involves geologic periods and not a few thousand years.

CHEMICAL COMPOSITION OF THE GROUND WATERS.

TYPES OF GROUND WATER.

The wells in San Joaquin Valley north of Tulare County yield three general types of water in relation to geographic position. The east-side and west-side types, named, as may be inferred, from their

[1] Dole, R. B., and Stabler, Herman, Denudation: In U. S. Geol. Survey Water-Supply Paper 234, p. 80, 1909.

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position in the valley, are distinguishable from each other particularly by their difference in content of sulphate (SO_4), and the intermediate or axial type, occurring along the strip between the areas of typical east-side and west-side waters and blending into them, is distinguishable chiefly by its relatively high content of alkalies. As this geographic grouping greatly facilitates understanding of the general characteristics of the ground supplies and their usefulness discussion of it has been taken up in as much detail as the assays warrant. When the determinations of sulphate are plotted on a map, as in Plate II (in pocket), it is seen that nearly all the waters high in sulphate and no waters low in sulphate were found on the west side; and that very few waters on the east side north of Kern County contain more than 10 parts per million of sulphate. Waters high in sulphate are scattered over the east side of Kern County, but not enough tests were made to warrant definite conclusions regarding their distribution, and the following statements therefore relate particularly to conditions in the area north of that county.

CONDITIONS NORTH OF KINGS RIVER.

OCCURRENCE OF SULPHATE AND NONSULPHATE WATERS.

Water from wells less than 1,200 feet deep contains 80 to 2,000 parts per million of sulphate in the area west of the limit indicated by A′A′ in Plate II (in pocket). The quantity of the radicle is usually less in the northern part than in the broad plains south of Newman, where arid conditions of water supply are more nearly approached. A decrease from west to east in the quantity of sulphate is noticeable in most of the western area, but there are many exceptions to this relation, and it is not nearly so striking as the abrupt change that occurs between the limits indicated by lines A′A′ and C′C′ (Pl. II). Wells more than 200 feet deep east of the limit indicated by C′C′ yield water containing not more than 10 to 20 parts per million of sulphate and usually not more than 5 parts. Wells 200 to 1,000 feet deep were tested all over the eastern part of the valley; a well 2,500 feet deep at Stockton, one 1,800 feet deep at Corcoran, one 1,400 feet deep near Pixley, and a 1,300-foot well near Madera also were tested and none yields water carrying more than 10 parts of sulphate. It may be concluded, therefore, that this is a general condition applying to the entire eastern area north of Kern County. The water of wells less than 200 feet deep in the same territory north of Kings River contains practically no sulphate, but south of that river in Kings and Tulare counties high sulphate occurs in the water of shallow wells for a few miles east of the axis, and then abruptly disappear to recur in the water of only a few scattered wells between there and the foothills of the Sierra. The four waters that

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were found to contain much sulphate far east of the axis in Tulare County are from wells in areas that have not been irrigated, and the ground around them shows accumulations of white alkali. The wells probably penetrate interdelta areas where alkali salts have been deposited by evaporation, and their waters might be improved by the leaching effect of irrigation accompanied by drainage. East of the boundary indicated by line B'B' (Pl. II) sulphate does not occur in appreciable amount in the water of wells less than 200 feet deep except in the few scattered areas of Tulare County.

The boundary indicated by A'A' parallels San Joaquin River and Kings River Slough, lying one-half to 6 miles west of them from San Joaquin Bridge to Tulare Lake. The boundary indicated by C'C' runs in the same general direction, passing just west of Stockton, Modesto, Livingston, Lemoore, and Angiola. Boundary B'B' lies between A'A' and C'C' from Stockton to Lemoore, where it crosses C'C', diverging gradually from it and ultimately curving in a broad sweep eastward to the foothills. These boundaries do not show the exact limits of the areas of sulphate-bearing waters within 2 or 3 miles east or west, but in view of the large number of tests it is fairly certain that wells 1,200 feet or less in depth west of boundary A'A' yield sulphate waters and that wells less than 1,200 feet and probably those 2,000 or more feet deep east of boundary C'C' yield nonsulphate waters. Between these two boundaries, which separate the areas of typical east-side and west-side waters, lies a strip 3 to 15 miles wide in the axis of the valley, where the change in sulphate content occurs. North of Kings River the change in the water from wells of the same depth along parallels is abrupt, and the farther the wells are from the west side of this strip in the axis the deeper they can be bored without striking sulphate water.

CAUSE OF THE DIFFERENCE IN COMPOSITION OF WATER.

This essential difference in the chemical composition of the ground waters is traceable to the structure of the plain. Geologically San Joaquin Valley is a deep trough that has been filled to its present level by material washed down from the slopes of the mountains bounding it, and the chemical characteristics of the filling material are essentially those of the rocks from which the material has been derived. The rocks of the Sierra are principally granites and metamorphic igneous slates and schists. These hard, difficultly soluble rocks and the sedimentary rocks derived from them that lie along the eastern foothills as far south as Madera County and also in Kern County have supplied to the valley material that is in turn capable of yielding little mineral matter to water percolating through it; consequently the areas of east-side débris furnish ground waters

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notably low in all mineral constituents. On the other hand, the rocks of the Coast Range, consisting largely of Cretaceous shales and sandstones and the calcareous gypsiferous shales, sandstones, and clays derived from them are much more soluble, and the filling material of the west side of the valley is therefore distinctly different from that of the east side. The water that passes through the west-side alluvium becomes highly impregnated with mineral matter and constitutes a distinct type of supply whose essential characteristic is the presence of large quantities of sulphate and correspondingly large quantities of bases.

CONTACT ZONE OF SULPHATE AND NONSULPHATE WATERS.

In order to trace more closely the boundaries of these characteristic types of water cross sections have been plotted along the east and west lines indicated in Plate II (see cross sections AB to MN, inclusive, Pl. III). The numbers on the cross sections represent the amounts of sulphate found in the ground waters. The position of the dot near each number in reference to the surface profile corresponds to the depth of the well, and its position in reference to the vertical axis corresponds to the distance of the well from the west side of the valley, all the cross sections originating at the foothills of the Coast Range. Dotted lines aa′ indicate the known eastern boundaries of zones of sulphate water and dotted lines bb′ the known western boundaries of zones of water very low in sulphate. The width of the uncertain strip between aa′ and bb′ obviously differs in the several sections according to the available information regarding quality. Solid lines cc′ indicate in each section the probable junction between the zones of sulphate and nonsulphate water, and the degree of uncertainty of its location is clearly indicated by its relation to the other lines. The upper end of boundary cc′ is located on the west side of the present beds of the axial watercourses in all the sections except IJ and MN, though the uncertain strip is 2 to 10 miles wide at the surface except in section MN. This apparently empirical location of the boundary is explainable by the fact that local information indicates the sulphate or nonsulphate character of the water near the surface in many places where tests could not be made. No analyses of water along the location of section AB are available on the west side nearer the river than Banta, but the poor quality of two waters less than 2 miles west of the river was evident from their taste. In section CD, aa′ is very near the location of the river, and east of Newman and Los Banos and at Mendota (sections EF, GH, and KL) shallow borings, when they contain water, are currently reported to yield highly mineralized supplies. Therefore it is probable that cc′ should have about the surface location indicated. The abrupt change in character of the waters is not absolutely demonstrated for

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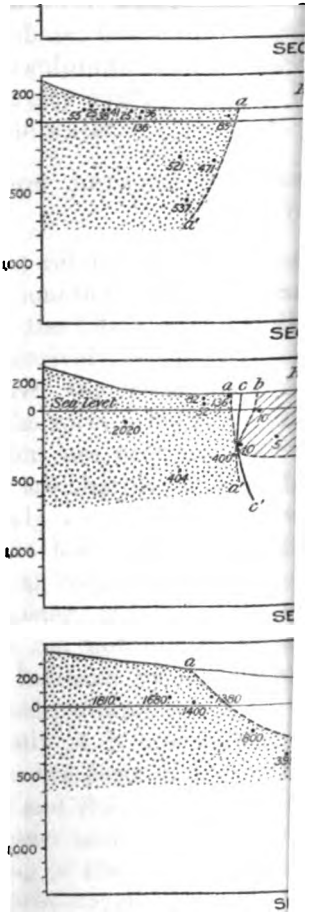

CROSS SECTIONS SHO

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the entire distance from San Joaquin Bridge to Kings River, but that the transition is effected very quickly in some regions is shown by the data in sections IJ and MN, in which the sulphate content of the ground waters drops from 100 to 500 parts per million down to practically nothing within 2 or 3 miles.

In all the sections cc′ dips eastward; that position is clearly established in sections EF, KL, and MN, and comparison of data for wells near the other sections but not included in them shows the probability of a generally similar dip everywhere between San Joaquin Bridge and Kings River. The dip of cc′ explains why some shallow wells near the axis yield better water than deep ones. For example, wells of any depth less than 600 feet in Newman (see section EF, Pl. III) yield water high in sulphate; in Stevinson Colony, a few miles farther east, however, water from wells less than 80 feet deep contains almost no sulphate, but water from wells exceeding 250 feet in depth is as high in sulphate as that in Newman, and a well in Livingston or east of that city could probably be drilled to any depth without striking sulphate water.

RELATION BETWEEN THE CHARACTER OF THE WATERS AND THE ORIGIN OF THE SILTS.

What relation the boundary between these types of water bears to the junction of the east and west encroachments of silt deposited during the filling of the valley is a geologic problem that need not be extensively considered. It is significant that the present bed of the river, the lowest part of the land surface, coincides so nearly with the surface boundary between the types of ground water. As silts that are now transported to the axis from both sides of the valley are sharply divided from each other by being diverted to a northerly course at the river ground waters moving toward the axis—at least those near the surface—would be differentiated in chemical composition because the sediments through which they are passing are derived from rocks of different character. Such waters can not mingle to any great extent both because of their being balanced by hydrostatic pressure and because of their diversion underground to follow the northerly course of the river. Consequently it is reasonable to conclude that the bed of the river always has been the junction line of the two apposed influxes of débris and that the line of demarcation between the types of water represents successive positions of the river channel during the upbuilding of the valley. Such supposition readily explains the comparatively sharp change in the character of the waters, a condition that would not exist if the east-side waters had pushed westward into the west-side sediments or if the west-side waters had entered the east-side sediments. The westward migration of the bed of the

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stream is caused by the greater proportion of silt contributed by the east-side streams because of their greater discharge and the more rapid upheaval of the Sierra.

The only well on the west side found to contain very little sulphate is 2,250 feet deep and in sec. 14, T. 18 S., R. 18 E., midway between the locations of cross sections MN and OP and about 3 miles west of Kings River Slough. This apparent lack of sulphate in the waters of the deep sediments on the west side indicates the presence of sediments like those of the east side below the typical material of the west side, but as no other well approaching this one in depth could be found, this single test does not furnish sufficient evidence for definite conclusions.

CONDITIONS AROUND TULARE LAKE.

CONTACT ZONE OF SULPHATE AND NONSULPHATE WATERS.

The relations between the east-side and west-side types of ground water change materially near the outlet of Kings River. Shallow wells bordering the north and east shores of Tulare Lake yield water high in sulphate and other constituents, but deep wells in the same area yield water exceptionally low in all constituents, including sulphate. The reason for this apparently confused condition can be made clear by consideration of the cross sections depicted in Plate III and figure 3. The section indicated by OP (Pl. III) starts at the foot of the hills west of Huron, crosses Kings River Slough southwest of Lemoore, and passes through Hanford. The sections indicated by QR, QS, and QT have their origin at a common point in T. 21 S., R. 18 E., and radiate across the basin of Tulare Lake, passing, respectively, south of Stratford, through Tulare, and north of Angiola. Lines aa′, bb′, and cc′ represent, respectively, the known eastern boundary of sulphate water, the known western boundary of nonsulphate water, and the probable contact between those two types of water.

The relations between aa′, bb′, and cc′ in sections OP–QT indicate that the overlapping of the zone of sulphate-bearing waters is due to saline material that has been deposited in the lake bed during successive evaporations of the lake water. Kern, Kaweah, and other rivers now regularly or intermittently tributary to Tulare Lake formerly discharged their waters north toward San Joaquin River, but the outpushing delta of Kings River, gradually cutting off the higher end of the valley, formed the basin of Tulare Lake and altered the river courses. Shallow Tulare Lake, which fluctuates greatly in area, has been completely dry within recent years, and undoubtedly similar periods of low water and dryness have been often included in the history of the lake since its formation. After the water has

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been removed by evaporation the mineral substances thus left behind have strongly impregnated the bed with salts, which later influxes of silt have partly covered and protected from resolution. Thus as the valley has been built up the lake basin has been filled with alter-

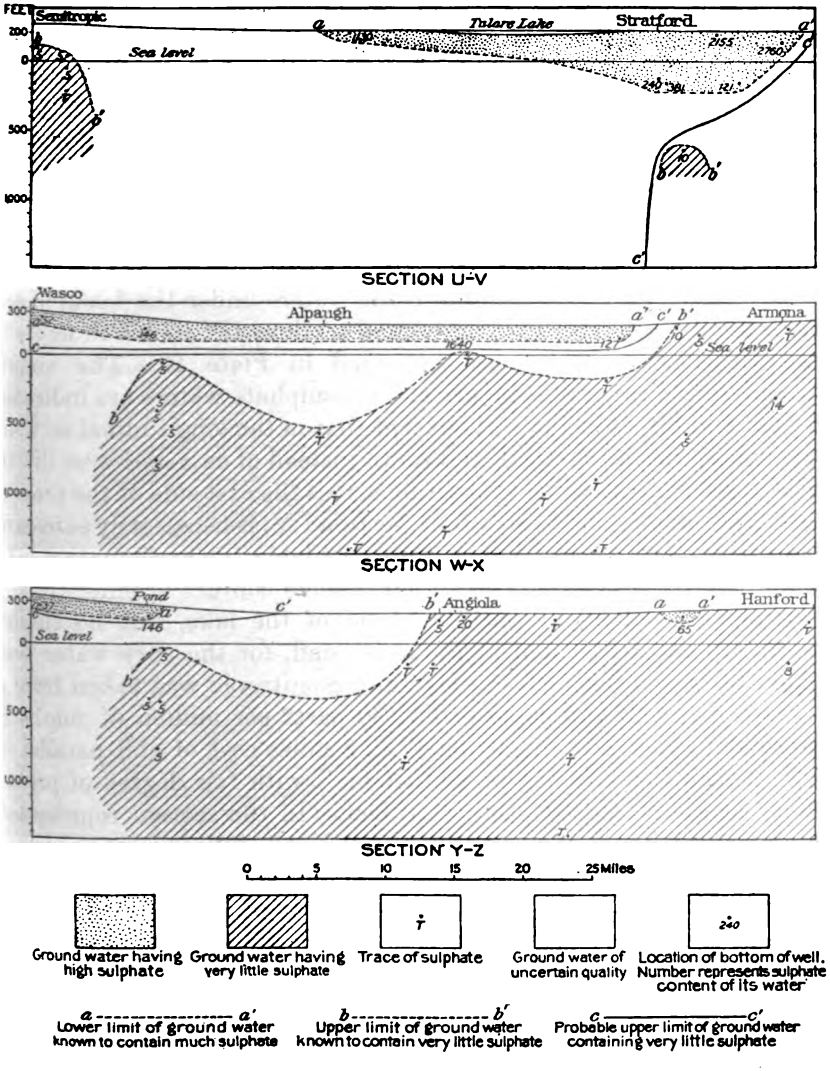

FIGURE 2.—Longitudinal sections showing sulphate content of ground water in the vicinity of Tulare Lake.

nating or mixed layers of silt and saline deposits that now yield highly mineralized waters to wells entering them. Wells that pass completely through the old lake beds on the east side reach sediments capable of furnishing excellent supplies because they are unmixed with the saline deposits. Therefore aa′ in sections OP–QT marks

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not only the known east boundary of the zone of sulphate water, but also the known boundary of the zone of saline impregnation, while cc′ shows the probable boundary between the east-side and west-side types of water for part of its length and the boundary between the east-side and the superimposed "lake residue" waters for the remainder. The correct position of dd′, indicating the probable western boundary of the lake deposits, is highly uncertain, but the eastern boundary of the zone affected by the lake residues is fairly well fixed by the results of tests of water from shallow wells. It runs southeast from Lemoore (see B′B′, Pl. II) to Corcoran, thence to Angiola, beyond which its location is not well defined. One well 40 feet deep east of B′B′ in sec. 1, T. 19 S., R. 21 E., yields water containing 65 parts per million of sulphate, but this doubtless enters a small isolated tract of alkali.

The distribution of sulphate in the waters under the basin of the take is portrayed also by longitudinal sections UV to YZ in figure 2, the locations of which are indicated in Plate II. The known boundaries of zones of sulphate and nonsulphate waters are indicated by aa′ and bb′ as in Plate III except that in the longitudinal sections the boundaries mark north and south instead of east and west limits. The "uncertain area" in the section across the east side of the present lake from Semitropic to Stratford (section UV) is necessarily extensive because so few ground waters were available for examination. In the same section cc′ indicates the probable contact of sulphate and nonsulphate waters at the north end of the lake, but no similar boundary can be located at the south end, for the only water that could be tested between the lake and Semitropic was taken from a 20-foot dug well and contained 1,130 parts per million of sulphate. More abundant data in section WX, 8 miles east of and parallel to UV, permit location of the contact (cc′) with fair degree of probability at an average depth of 170 feet. In the section represented by YZ, 3 miles east of and parallel to WX, the influence of the lacustrine deposits does not appear. The sulphate water in one well near Hanford probably comes from a small spot of alkali. The shallow wells in the southern part of this section are affected by the sediments of different character in Kern County.

TOTAL MINERAL CONTENT OF WATERS.

Additional evidence that the highly mineralized condition of the aquifers under the lake is caused by saline residues is afforded by the results of other tests besides those for sulphate. All excessive amounts of chloride and bicarbonate in ground waters near the lake were found either west of or almost exactly in the position indicated by bb′ (Pl. III), a fact indicating that bb′ represents the eastern limit of the zone of highly mineralized waters and also indicating concen-

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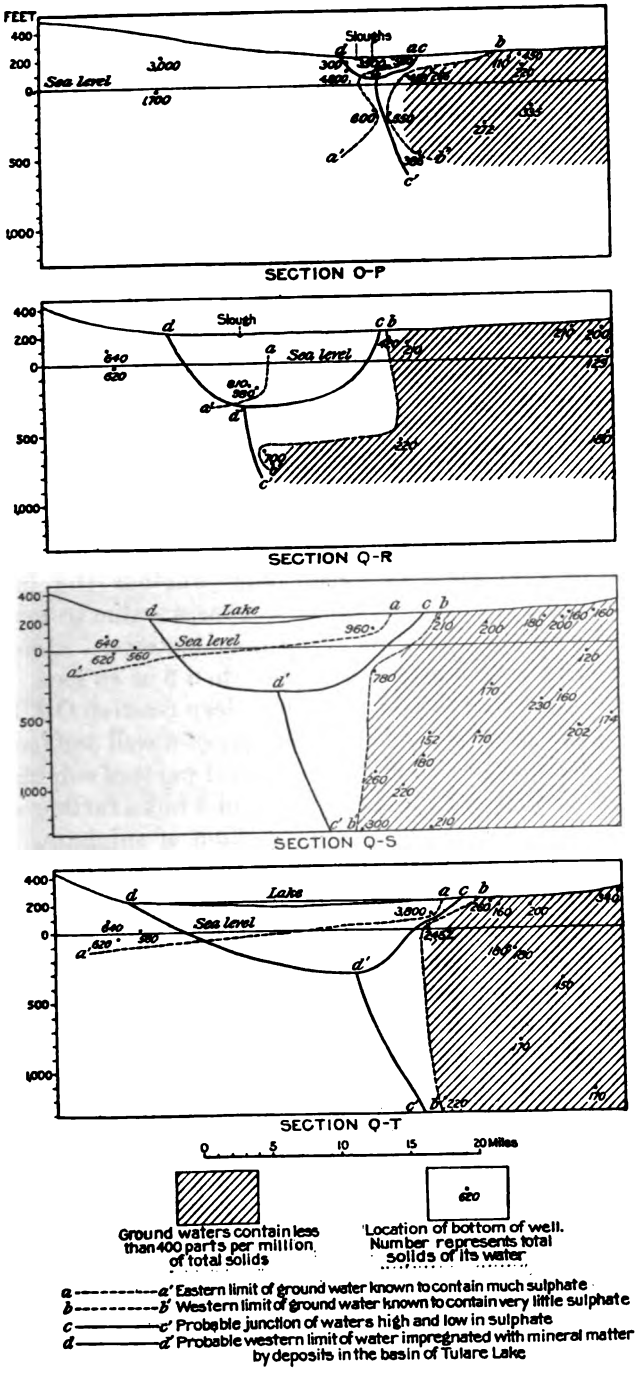

FIGURE 3.—Cross sections showing mineral content of ground water in the vicinity of Tulare Lake.

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tration and deposition from highly saline solutions as the causes of the impregnation of the shallow waters with mineral matter.

The relation of the total mineral content of the waters to the probable boundaries of the old lake basin is graphically summarized in figure 3. The boundaries aa′, bb′, cc′, and dd′ in these four sections are those shown in Plate III, but the figures give the calculated total mineral content of the waters. All waters from the alluvium above the boundary indicated by dd′c are high in mineral content and waters from wells west of the lake are, of course, also high for the west side is normally a region of high mineral content. The bottoms of five wells yielding water containing more than 400 parts of total solids are in the boundary indicated by bb′ (fig. 3), but no well whose water exceeded that amount was found in the eastern part of the area.

THICKNESS OF THE LACUSTRINE DEPOSITS.

The maximum thickness of the lacustrine deposits is not entirely established because of the limited range of depth of wells that could be tested and because of uncertainty whether the high mineral content of wells near the middle of the basin is due to mineralization by typical west-side alluvium or by lake deposits. Along boundary B′B′ (Pl. II) the thickness is not more than 8 or 10 feet. Southwest of Lemoore the water of a well 375 feet deep (section OP, Pl. III) contains 121 parts of sulphate, and the water of a well 386 feet deep near Stratford (section QR, Pl. III) contains 381 parts of sulphate, but that of an 850-foot well as near the slough and 3 miles farther north yields water containing only 10 parts per million of sulphate. The water of a 95-foot well (section QS, Pl. III) in sec. 25, T. 20 S., R. 21 E., contains 127 parts of sulphate, and that of a 400-foot well near by practically none; the water of a 102-foot well in sec. 23, T. 22 S., R. 22 E. (section QT, Pl. III), contains 1,640 parts, and that of a 216-foot well in the next section practically none. It may be concluded that the maximum thickness of the lacustrine deposits is certainly not less than 100 feet nor greater than 850 feet and probably about 400 feet and that the thickness is much less near the edges of the basin. Boundaries cc′ and dd′ have been located in sections OP to QT inclusive (Pl. III) in accordance with these conclusions.

PROPER DEPTH OF WELLS NEAR TULARE LAKE.

Plate IV shows the depths to which wells near Tulare Lake should be sunk in order to strike water of good quality. The purple contour lines, indicating the depth in feet below which waters containing sulphate or excessive amounts of other mineral constituents will probably not be encountered, have been located in accordance

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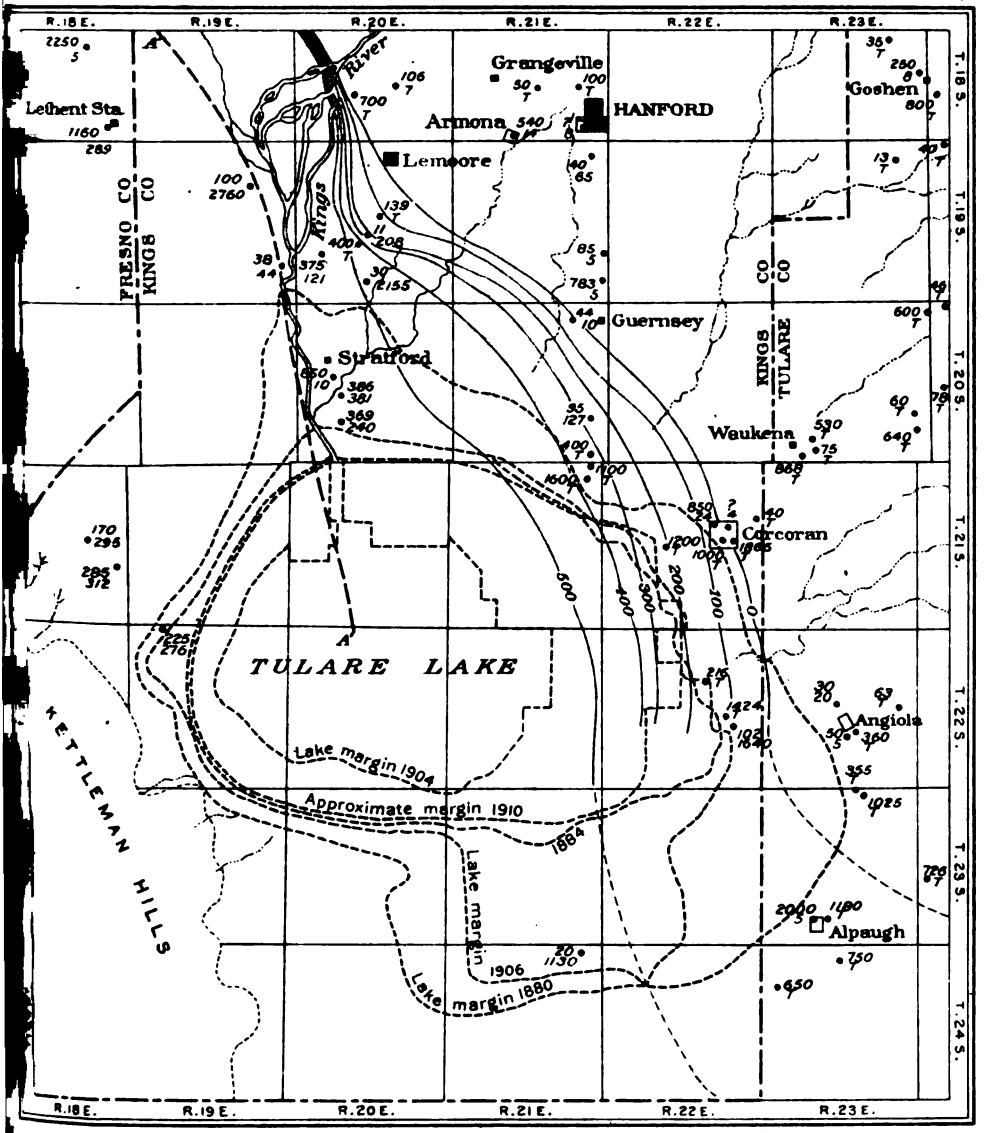


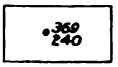
MAP OF TULARE LAKE AND VICINITY, CALIFORNIA

Showing depth to which sulphate water may be obtained and location of wells from which water was tested

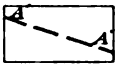
5 0 5 10 Miles

1915

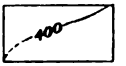
LEGEND



Location of well from which water was tested. Black number indicates depth in feet; purple number indicates sulphate content of water in parts per million. T signifies trace of sulphate



Line west of which ground waters contain large amounts of sulphate (*Reproduced from Plate II*)



Contours indicating deptn in feet below which sulphate waters will probably not be encountered (*Wells should be bored 50 to 100 feet deeper to assure good water*)

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with the data in sections OP to YZ, inclusive of Plate III and figures 2 and 3. Dependence has necessarily been placed in the reported depths of wells. Boundary A'A' corresponds to boundary A'A' indicated in Plate II.

For safety wells should be sunk 50 to 100 feet deeper than the depths indicated by the contours, and as practically all the water in the upper strata is highly impregnated with mineral matter the casings should be tight down to the good water. Though it is not known how far west of the location of the 500-foot contour wells can be drilled without encountering sulphate water, line A'A' represents the extreme western limit of nonsulphate water at all depths, and the safe limit even for deep wells is probably not beyond the middle of the lake, the shore of which in 1910 is shown by a dotted line located from personal observation and local report without instrumental data. Within the area near Tulare Lake designated as yielding nonsulphate water spots may be found where supplies of poor quality may be afforded by deep wells, but such spots will be small. Information regarding the quality of ground waters immediately south of Alpaugh is scanty.

CONDITIONS SOUTH OF TULARE LAKE.

Data on the quality of ground water in Kern County are restricted to so few areas that conclusions can be formed only in respect to local characteristics, the analyses being discussed in more detail on pages 292–294. The water of wells 200 to 1,000 feet deep at Pond, Semitropic, Buttonwillow, and Oil Center contains little sulphate, but the deep water in the basin of Kern Lake contains some, and nearly all ground water southeast of Bakersfield to a depth of at least 300 feet seems to contain much sulphate. A well 686 feet deep 6 miles west of Buttonwillow, whose water carries 49 parts per million of sulphate, may mark the eastern boundary of the west-side type of water. Contrary to conditions farther north, many shallow waters in the east part of the valley in Kern County are rather high in sulphate and other substances. This high mineral content may be due to the influence of the Pliocene and Miocene sediments at the base of the Sierra, which in Kern County are different in texture and composition from those north of Madera County.

Cretaceous rocks are plentiful and the ground waters are notoriously bad in the foothills south of the basin of Kern Lake. Therefore, the high sulphate content of ground water in the adjacent portions of the valley is probably caused by the character of the silt washed down from the hills as well as by concentration similar to that which has occurred in the basin of Tulare Lake. The data

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in section D'E' (fig. 4) indicates a gradual increase of mineral content of the ground water from north to south across the basin of Kern Lake, the bed of which is now dry and under cultivation. The deep waters under the lake bed contain measurable quantities of sulphate, but none is particularly high in dissolved solids, and all are greatly superior to the shallow waters around Tulare Lake. This more favorable condition is explained by the fact that the Kern basin has not been landlocked so long as that of Tulare Lake.

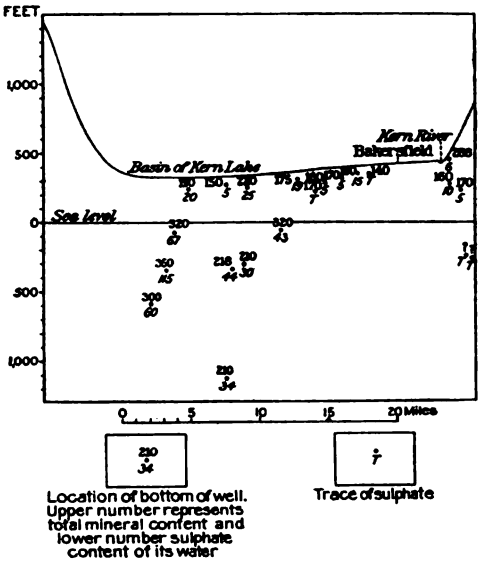

FIGURE 4.—Section D'E', showing content of sulphate and total mineral matter of ground waters in the basin of Kern Lake.

COMPOSITION AND QUALITY OF EAST-SIDE WATERS.

Ground waters distinctly of the east-side type occur east of the boundaries indicated by B'B' and C'C' in Plate II (in pocket), and the location and significance of these boundaries have been discussed (pp. 100–104). Wells less than 1,100 feet deep in the east side north of Kern County yield waters much alike in total mineral content and in composition. These waters are the best ground supplies in the valley, being usually acceptable for all purposes and belonging almost exclusively to the calcium carbonate class [1] typical of humid and semihumid regions. On the east side near the axis sodium carbonate and some sodium chloride waters are found, but sulphate waters are found only in a few widely separated tracts in Tulare County. The averages in Table 22 show the characteristics of the east-side waters and their similarity to each other.

[1] For the explanation of this and similar terms defining the character of water see p. 80.

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TABLE 22.—*Average chemical composition and quality of water from wells 20 to 1,100 feet deep east of the boundaries indicated by B'B' and C'C' in Plate II.*

[Parts per million except as otherwise designated.]

	San Joaquin County.	Stanislaus County.	Merced County.	Madera County.	Fresno County.	Tulare County.	Average.	Limits of individual determinations.	
								Highest.	Lowest.
Number of analyses	40	21	26	20	34	67	[a] 208	.....	.....
Carbonate radicle (CO_3)	0	0	0	0	0	Tr.	0	18	0
Bicarbonate radicle (HCO_3)	160	160	140	125	135	140	140	344	35
Sulphate radicle (SO_4)	5	Tr.	Tr.	4	4	8	4	202	Tr.
Chlorine (Cl)	35	50	25	40	20	35	35	490	4
Sodium and potassium (Na+K)	35	35	30	20	30	40	30	500	4
Total hardness as $CaCO_3$	140	140	100	120	70	100	110	500	4
Total solids	280	310	210	220	210	240	240	1,500	50
Alkali coefficient (k) (inches)	50	60	60	60	70	40	60	400	4
Scale-forming constituents (s)	180	190	140	160	130	140	160	460	40
Foaming constituents (f)	100	90	80	60	80	110	90	1,000	0

[a] Total.

The averages, which have been computed from the results of the assays, are arranged in geographic order from north to south, and they are graphically represented in Plate V (p. 120). Tests were made for carbonate, bicarbonate, sulphate, chloride, and total hardness, and the other quantities are computed from the results of those tests. The mean of 208 analyses represents a water moderate in total solids, fairly hard, and without distinct taste due to mineral matter, and therefore unobjectionable from a chemical standpoint for domestic use; such water would be fair for boiler use, as it contains only a moderate amount of scale-forming matter and little foaming matter; and it would be entirely acceptable for irrigation. The averages by counties represent waters of the same type, for the differences in some of the constituents are not great enough to have particular significance. The apparent tendency toward decrease southward in hardness and bicarbonate may be explained by the decrease in rainfall, which results in a decrease in the quantity of carbon dioxide supplied by decaying vegetation. The last two columns of Table 22 show that local fluctuations in quality are far greater than the differences in the county averages, and they indicate that there is considerable latitude for selection when supplies of lowest mineral content are necessary. The fluctuations are much greater in Tulare County than in any other part of the region. Altogether the waters of wells less than 1,100 feet deep are more nearly uniform in quality throughout the east side than in any other part of the valley.

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TABLE 23.—*Chemical composition of water from wells more than 1,100 feet deep east of the boundaries indicated by B′B′ and C′C′ in Plate II.*

[Parts per million except as otherwise designated.]

	San Joaquin County.	Madera County.	Fresno County.	Tulare County.
Carbonate radicle (CO_3)	0	0	Tr.	18
Bicarbonate radicle (HCO_3)	110	137	417	68
Sulphate radicle (SO_4)	5	Tr.	Tr.	5
Chlorine (Cl)	2,900	1,160	135	15
Sodium and potassium (Na+K)[a]	1,300	485	240	50
Total hardness as $CaCO_3$	1,650	776	47	8
Total solids[a]	5,900	2,000	610	170
Depth of wells (feet)	1,200 to 2,500	1,310	1,200	1,400

[a] Computed.

East-side wells more than 1,100 feet deep yield water entirely different in composition from that of shallower wells. Four wells, 1,200 to 2,500 feet deep, in San Joaquin County yield salt water unfit for use. (See Table 23.) The 1,310-foot well near Madera supplies salt water much lower in mineral content than that from the deep wells in San Joaquin County. The 1,200-foot well east of Wheatville, Fresno County, yields water much lower in chloride and all other constituents, but carbonate is so high that the water is poor for irrigation. The supply of the 1,400-foot well in T. 22 S., R. 24 E., represents conditions in Tulare County, where some of the best waters are struck at depths greater than 1,100 feet. This sodium carbonate water is low in mineral content and fairly acceptable for boiler supply and for irrigation. It is important to note that neither this well nor those as deep as 2,000 feet near Tulare Lake encounter salt water, as do wells of similar depth near Stockton.

COMPOSITION AND QUALITY OF WEST-SIDE WATERS.

GENERAL CHARACTER.

Typical west-side ground waters occur west of the boundary indicated by A′A′ in Plate II (in pocket). They are not so uniform in mineral content as the waters of the east side, but they are much higher in mineral content, and they are characterized by high percentages of sulphate. Calcium sulphate or gypsum waters occur generally near the foothills of the Coast Range, and sodium sulphate waters near the axis of the valley. The west-side supplies as a class are so highly mineralized that they are very hard and are unsuitable for boiler use without purification. Nearly all of them have a distinct "alkali" taste and many are unpalatable. Fortunately, however, the sulphate nature of the dissolved matter makes it relatively less harmful to crops, and comparatively few supplies are absolutely unfit for irrigating lands.

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QUALITY IN RELATION TO GEOGRAPHIC POSITION.

The quality of the west-side ground waters differs so much from place to place that no more definite description of the waters as a class can be given than that in the preceding paragraph. The region has, therefore, been roughly divided into districts, in which the supplies are more or less comparable with each other, for, unlike the waters of the east side, the waters of the west side are dependent in quality more on geographic position than on depth. The averages of analyses of water in each district, presented in Table 24, indicate approximately the character of the west-side supplies and the differences to which they are subject. The last column, giving the average quality of ground waters on the east side of the valley, has been added for comparison. The total mineral content of water in each district is graphically represented in Plate V (p. 120).

TABLE 24.—*Average chemical composition and quality of ground waters west of the boundary indicated by A'A' in Plate II.*

[Parts per million except as otherwise designated.]

	San Joaquin County near foothills.	San Joaquin County between Tracy and San Joaquin River.	Stanislaus County.	Merced County northwest of Los Banos.	Merced County southeast of Los Banos.
Number of analyses	5	15	21	14	9
Carbonate radicle (CO_3)	Tr.	Tr.	Tr.	Tr.	Tr.
Bicarbonate radicle (HCO_3)	180	190	220	240	180
Sulphate radicle (SO_4)	690	200	220	70	330
Chlorine (Cl)	300	75	300	60	440
Sodium and potassium (Na+K)[a]	340	50	130	50	360
Total hardness as $CaCO_3$	620	280	400	250	380
Total solids[a]	1,800	640	930	510	1,530
Alkali coefficient (k) (inches)[a]	4	30	21	40	6
Scale-forming constituents (s)[a]	650	310	420	300	410
Foaming constituents (f)[a]	900	230	340	150	960

	Fresno County northwest of Mendota.	Fresno County near foothills south of Mendota.	Fresno County near slough south of Mendota.	Kings County.	Average quality of east-side waters.
Number of analyses	7	7	10	3	208
Carbonate radicle (CO_3)	Tr.	0	0	Tr.	0
Bicarbonate radicle (HCO_3)	150	145	250	70	140
Sulphate radicle (SO_4)	1,140	1,160	420	290	4
Chlorine (Cl)	220	130	70	50	35
Sodium and potassium (Na+K)[a]	350	240	240	110	30
Total hardness as $CaCO_3$	900	1,040	250	170	110
Total solids[a]	2,300	2,100	1,030	610	240
Alkali coefficient (k) (inches)[a]	9	12	20	25	60
Scale-forming constituents (s)[a]	950	840	280	240	160
Foaming constituents (f)[a]	900	640	660	310	90

[a] Computed.

The waters of five wells, 46 to 268 feet deep, in San Joaquin County between Tracy and the western foothills belong to the sodium sulphate class, and they carry 900 to 2,500 parts per million of min-

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eral matter, 250 to 960 parts of which is sulphate. They are poor for irrigation and too high in scale-forming and foaming constituents to be fit for boiler use.

Alkalies predominate in some of the 15 waters from widely scattered wells 20 to 400 feet deep in the same county south and east of Tracy and west of San Joaquin River, but most of the waters belong to the calcium sulphate class. All would be considered poor for boilers because they would form large quantities of hard scale and would cause foaming. They are better than the waters near the foothills, however, and they are low enough in mineral matter to be suitable for irrigation. Depth bears no apparent relation to quality, except that in certain sections the shallow supplies are somewhat worse than the deep ones.

The part of Stanislaus County between San Joaquin River and the western foothills is narrower than the rest of the west side, and consequently the normal ground water there is affected by mixture with the more highly mineralized water that is slowly percolating northward from farther south in the valley. The 21 supplies that were tested in western Stanislaus County differ greatly from each other in composition, ranging from the calcium sulphate to the sodium chloride type. The artesian waters near San Joaquin River, like those in Stevinson colony across the river, are salty, rather poor for irrigation, and capable of foaming in boilers. Wells 20 to 200 feet deep throughout the region yield supplies containing chlorine in amounts ranging from 15 to 300 parts without apparent regularity. Most of the waters could be used for irrigation, but none is good for boiler use because of the high content of scale-forming and other ingredients.

Conditions in Merced County are similarly complex and irregular. West and north of and including Los Banos 14 wells, 23 to 580 feet deep, yield better water than wells southeast of that city. Sulphate is lower than in other parts of the west side and chloride likewise is moderate, but both radicles are always present in appreciable amount. The waters generally can be used for irrigation without causing trouble by their mineral content, but they need to be softened before being used in boilers. Waters from different depths show irregular local differences of quality.

The ground supplies southeast of Los Banos are poorer than those northwest of that city, and resemble those of northwestern Fresno County. They are strong sodium sulphate and sodium chloride waters that range from fair to very poor for irrigation. Their contents of foaming and scale-forming ingredients are so great that they are poor for boiler use, and some of them are industrially useless. A few shallow wells near irrigation ditches yield water better than the average.

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The broad flat west side of Fresno County, at present occupied by sheep ranches and a few isolated farms, did not afford much opportunity for investigation, but the results of the tests that could be made make it apparent that this region yields the hardest and most strongly mineralized ground waters in the west side of San Joaquin Valley. Most of the wells near San Joaquin River and Kings River Slough yield sodium sulphate waters lower in mineral content than those farther west. Ten waters from wells thus situated and 20 to 1,100 feet deep contained 600 to 1,700 parts per million of total solids. All would be likely to foam in boilers and could be distinctly improved by being purified before use. Most of them could be applied in irrigation under proper conditions of drainage to prevent alkali accumulation.

The waters farther west in Fresno County are very high in sulphate and alkaline earths; that is, they are gypsum waters. Though this makes their content of incrustants so high that they are very bad for boiler use, it does not influence to so great extent their value for irrigation, and many of them could irrigate crops if proper precautions for drainage were taken. Few shallow wells on the plains yield water, wells usually being 100 to 700 feet deep, and it is improbable that any better water would be encountered by boring deeper. A well 2,250 feet deep yields sodium chloride water high in carbonate and very poor for irrigation or for boilers. The great quantity of gas in it makes it likewise unpalatable.

Three wells, 170 to 285 feet deep, west of Tulare Lake, in Kings County, were tested, one near the present shore of the lake and two about 5 miles from it. These waters contain considerably less dissolved constituents than the west-side waters of Fresno County, and they could be considered suitable for irrigation. They are high in sulphate, however, and the one farthest from the lake is a strong gypsum water.

Field work in the region south of Tulare Lake was not carried far enough west to make it certain that the true character of the ground waters in that part was discovered. A 20-foot dug well in sec. 1 (?), T. 24 S., R. 21 E., yields strong water high in sulphate, because it comes from the mineralized silt in the basin of Tulare Lake. No wells between that section and Semitropic could be sampled, but wells at the latter place yield water low in sulphate. Deep waters at Buttonwillow are low in sulphate, but those from wells 40 to 100 feet deep are high in sulphate, yet do not have the very high mineral content that is characteristic of ground waters in western Fresno County. Future investigation north and south of Lost Hills will probably show that the west-side belt of waters high in sulphate extends southward into Kern County, and that it terminates at its eastern boundary as abruptly there as in the counties farther north.

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DEPOSITION OF CALCIUM SULPHATE.

The figures in Table 24 (p. 113) indicate that in general the ground waters near the western foothills are calcium sulphate waters and that those farther east are sodium sulphate waters, the former containing much more mineral matter than the latter. This highly interesting alteration in the ground supplies that flow from the foothills of the Coast Range toward the axis of the valley evidently is the result of deposition of gypsum while the waters are passing through the ground. This phenomenon can be made clearer by means of the data in Table 25.

TABLE 25.—*The deposition of calcium sulphate from west-side waters.*

[Parts per million.]

Constituents.	Fresno County, southern part.		Fresno County, northern part.	
	A.	B.	C.	D.
Bicarbonate radicle (HCO_3)	145	250	140	184
Sulphate radicle (SO_4)	1,160	420	1,720	470
Chlorine (Cl)	130	70	140	400
Total hardness as $CaSO_4$	1,410	340	1,900	270
Alkalies (computed)	240	240	360	470
Total solids (computed)	2,100	1,030	3,000	1,700

Column A gives the average of analyses of water from 7 wells 80 to 400 feet deep near the foothills southwest of Mendota in Fresno County and column B a similar average for 10 wells 20 to 1,100 feet deep in a strip east of the 7 wells but west of Kings River Slough. These averages indicate that during the eastward passage of the water carbonate increases at the expense of the chloride and the alkalies remain unchanged. The decrease in total solids, 1,070 parts, is equivalent to the decrease in total hardness expressed as calcium sulphate; furthermore, the decrease in sulphate, 740 parts, is equivalent to 1,050 parts of calcium sulphate, or almost exactly the decrease in total solids. These striking relations make it evident that gypsum is being deposited from the ground waters; for if the change were one of simple dilution other constituents would be proportionately decreased, and if the alteration in character were caused by reaction between alkali salts in the silt and the calcium salts dissolved in the waters sulphate would not be decreased and the alkalies would be greatly increased. The figures in columns C and D afford a similar comparison of waters from wells in the northwestern part of Fresno County, column C giving the average of analyses of water from four wells 200 to 280 feet deep far out on the plains and column D giving the mean of analyses of water from two wells 437 and 532 feet deep near San Joaquin River. The decrease in sulphate, equivalent to 1,700 parts per million of calcium sulphate, is not completely equaled

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by the change of 1,630 in total hardness as calcium sulphate and of 1,300 in total solids, but these alterations are all of such magnitude in comparison with other changes that they lead to the conclusion that calcium sulphate is being deposited. North of Fresno County ground waters near San Joaquin River are affected in mineral content by seepage from the south and consequently any similar deposition that may occur there is effectually concealed.

COMPOSITION AND QUALITY OF AXIAL WATERS.

IRREGULARITY OF COMPOSITION.

The region of ground waters of the axial type can not be bounded so definitely as those of waters of the east-side and west-side types. It is included within the artesian area and it covers the territory between the boundaries indicated by A'A' and C'C' in Plate II (in pocket) overlapping on both sides and gradually merging into the areas in which other types predominate. As the axis of the valley or the lowest part of its trough receives the drainage of the valley ground waters there contain the highest proportion of the most readily soluble substances, the alkalies. On the west side sodium and potassium are left predominant among the bases after calcium sulphate has been removed from the ground water. On the east side the moderately mineralized calcium carbonate waters are strengthened by solution of alkali salts from the silts through which they slowly seep on their way from the foothills to the axis, and they are undoubtedly altered by drainage from irrigated lands. Carbonate is predominant on the east and sulphate on the west side of the axial belt, and both radicles are overshadowed by chloride in several localities. In general, the higher sodium content of waters from wells in the axis makes them less desirable for irrigation than that from wells on either side of the valley, and the same characteristic makes them more likely to foam when they are used for steaming.

The most noticeable feature of the axial waters is their wide range of concentration and composition, which is indicated in Plate V by graphic representation of the mineral content of water from wells of various depths in many localities. Nearly all wells in the axis near Tulare Lake yield sodium carbonate water, the deep supplies being much lower in mineral content than the shallower ones. Along Kings River Slough the mineral content of the ground waters is increased by the strong waters entering from the west side, and this influence continues northward for some distance along San Joaquin River.

CHLORIDE CONTENT OF ARTESIAN WATER.

Many deep wells along the axis north of Kings River yield brackish water, while wells away from the axis but just as deep and in the

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same latitude do not; this indicates the existence of local saline deposits in the moderately deep silts and the downward percolation of water charged with the soluble constituents of the silts. Very deep wells invariably yield salt water, a condition that may be explained by the broadspread occlusion of saline waters within the deeper layers of silt. As this likelihood of striking distasteful salty water, harmful in irrigation and corrosive to boilers, is a discouraging feature about putting down deep wells into the abundant artesian flow near the river, Table 26 has been prepared giving certain data regarding artesian waters that were tested between Lemoore and San Joaquin Bridge.

TABLE 26.—*Chloride content of water from artesian wells between San Joaquin Bridge and Lemoore.*

Location.			Depth (feet).	Chlorine (Cl) (parts per million).	Quality for irrigation.	Quality for boiler use.
Sec.	T.	R.				
Del Puerto Orestimba.			480	295	Fair.	Very bad.
Do.			350	250	do.	Bad.
Do.			285	430	Poor.	Do.
26	6 S.	9 E.	301	450	do.	Very bad.
31	6 S.	10 E.	600	1,000	Bad.	Do.
6	7 S.	10 E.	330	320	Poor.	Do.
25	7 S.	10 E.	250	2,080	Bad.	Do.
17	7 S.	11 E.	330	1,980	do.	Do.
13	9 S.	9 E.	402	150	Good.	Bad.
20	8 S.	11 E.	+500	1,520	Bad.	Very bad.
10	8 S.	12 E.	297	10	Fair.	Fair.
16	8 S.	13 E.	707	30	do.	Do.
27	8 S.	14 E.	325	10	Good.	Do.
36	9 S.	10 E.	350	139	Fair.	Bad.
36	9 S.	10 E.	660	372	Poor.	Do.
14	10 S.	11 E.	372	445	do.	Very bad.
Sanjon de Santa Rita.			320	35	Good.	Fair.
15	9 S.	13 E.	300	25	do.	Do.
21	9 S.	13 E.	340	20	Fair.	Do.
6	10 S.	14 E.	283	25	Good.	Do.
30	9 S.	15 E.	350	25	do.	Do.
21	11 S.	12 E.	550	1,155	Bad.	Very bad.
1	11 S.	12 E.	375	175	Fair.	Poor.
33	11 S.	13 E.	437	685	Poor.	Very bad.
35	9 S.	14 E.	240	20	Good.	Fair.
11	10 S.	14 E.	400	30	do.	Do.
22	13 S.	14 E.	532	115	Poor.	Very bad.
6	13 S.	15 E.	520	1,680	Bad.	Do.
34	11 S.	16 E.	+300	25	Good.	Fair.
32	11 S.	18 E.	1,310	1,160	Bad.	Very bad.
31	13 S.	15 E.	640	75	Fair.	Bad.
10	14 S.	16 E.	550	245	do.	Do.
12	15 S.	16 E.	700	65	Good.	Do.
19	15 S.	16 E.	700	55	Fair.	Do.
25	15 S.	17 E.	750	155	Poor.	Do.
9	15 S.	17 E.	800	265	do.	Do.
14	16 S.	17 E.	690	150	do.	Do.
8	17 S.	17 E.	1,100	35	Good.	Poor.
15	17 S.	18 E.	600	125	Poor.	Bad.
2	17 S.	18 E.	1,200	135	do.	Do.
36	18 S.	18 E.	1,178	40	Fair.	Do.
26	18 S.	20 E.	700	20	Poor.	Poor.
14	18 S.	18 E.	2,250	280	do.	Bad.

Thirteen artesian waters along Kings River Slough and within 6 miles of that watercourse were tested. (See Table 26.) Among these the water from the 2,250-foot well in T. 18 S., R. 18 E., containing 280 parts of chlorine, is practically useless. The water of a 550-foot well at Jamesan and of an 800-foot well south of that station are rather

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high in chlorine. The other ten waters, from wells 600 to 1,200 feet deep, are moderately low in chlorine and good to poor for irrigation, but undesirable for boiler use because of their high contents of foaming ingredients. Nearly all the artesian waters from wells less than 1,000 feet deep east of San Joaquin River and south of Dickersons Ferry are low in chlorine and are suitable for common use, but those west of the river in the same latitude are much poorer. Water from the 1,310-foot well in T. 11 S., R. 18 E., is high in chlorine and bad for general use. All deep waters around Newman and Stevinson Colony contain much chlorine. This condition extends south to Dickersons Ferry and north to Crows Landing, and probably no wells in that territory more than 300 feet deep will yield really satisfactory water. Water from shallow wells in Stevinson Colony is much better than that from deep wells.

No well more than 200 feet deep could be found between Crows Landing and Lathrop and therefore the quality of the deep axial waters in that area are unknown. The water of the 480-foot well at Crows Landing carries 295 parts per million of chlorine and is only fair for irrigation. The water of a 1,200-foot well near French Camp, just north of Lathrop, contains 1,735 parts of chlorine and is unfit for irrigation. Wells more than 1,200 feet deep at Stockton yield salt water while those 700 to 1,100 feet deep yield fresh water fair or poor for irrigation and shallower wells yield satisfactory fresh water.

The 1,310-foot well near Madera yields water containing 1,160 parts per million of chlorine. Therefore it may be concluded that any well more than 1,200 feet deep between Dickersons Ferry and Suisun Bay will yield salt water unsuitable for use. As the analyses show that the water of wells more than 400 feet deep near the axis between Dickersons Ferry and Crows Landing is salty and poor in quality, it is reasonable to conclude that wells 400 to 1,200 feet deep near the axis between Crows Landing and San Joaquin Bridge will also yield salty water. A similar conclusion regarding 500 to 1,000-foot wells 10 miles or more east of the river in Stanislaus and San Joaquin counties is, however, unjustifiable by the data at hand. It is possible that fresh water may be encountered between those depths as in eastern Merced and Madera counties, but no assertion to that effect can be made.

INCREASE OF MINERAL CONTENT FROM SOUTH TO NORTH.

GENERAL CONDITIONS.

Structurally, San Joaquin Valley is a trough filled with silt from the surrounding mountains. The ground waters, following the gentle but definite slope, percolate toward the axis and then follow the axis northward. They dissolve and retain in solution the more readily soluble substances with which they come into contact, and

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some of them deposit part of their load of less soluble constituents. These conditions lead to belief that the ground water gradually increases in mineral content as it progresses northward, or, in other words, that analyses of water from wells of equal depth should indicate an increase of mineral content from south to north. It is the purpose of this section to show how far the results of the tests support that belief.

Plate V shows graphically the amount of mineral matter in ground waters in different parts of the valley. Averages of analyses grouped by depth of wells have been used for the east side in order that the changes from county to county might be more clearly shown, but the results of individual tests have been plotted in the axis because the total solids there are so divergent. The only feasible grouping of analyses on the west side is by location. The length of the blocks indicates the amount of total solids and the shading indicates the depth of the wells. For the purposes of this diagram it has been convenient to accept the boundaries indicated by A'A' and C'C' in Plate II (in pocket) as the limits of the respective areas.

The diagram as a whole shows simply and forcibly the relations between location, depth, and mineral content of the ground waters. The east-side waters, low in mineral content, are remarkably uniform in quality down to a certain depth. The west-side waters are much more highly mineralized and are differentiated from each other principally by their distance from the foothills. The axial waters, extremely variable in character, are influenced by east-side and west-side waters and by soluble constituents in local sediments. The relations represented diagrammatically in Plate V explain several apparently inconsistent conditions of quality.

Briefly, the data establish that a progressive increase in the mineral content of the deep-seated underground drainage takes place, especially near the axis of the valley. No such relation exists in respect to the shallow waters, however, even near the median line of the trough, where the influence would be most clearly evident.

DEEP WATERS.

Analyses of water from wells more than 1,100 feet deep show a definite increase in mineral content from south to north proportionate to the increase in alkalies and chlorine; that is, the waters become more salty toward the outlet of the valley. Wells on the east side of Kern, Kings, and Tulare counties from 1,100 to 2,000 feet deep yield excellent water averaging about 200 parts per million of total solids. The water of the 1,200-foot well in sec. 2, T. 17 S., R. 18 E. is moderate in solids and in chlorine; the salty water of the 1,310-foot well in sec. 32, T. 11 S., R. 18 E. contains more than three times

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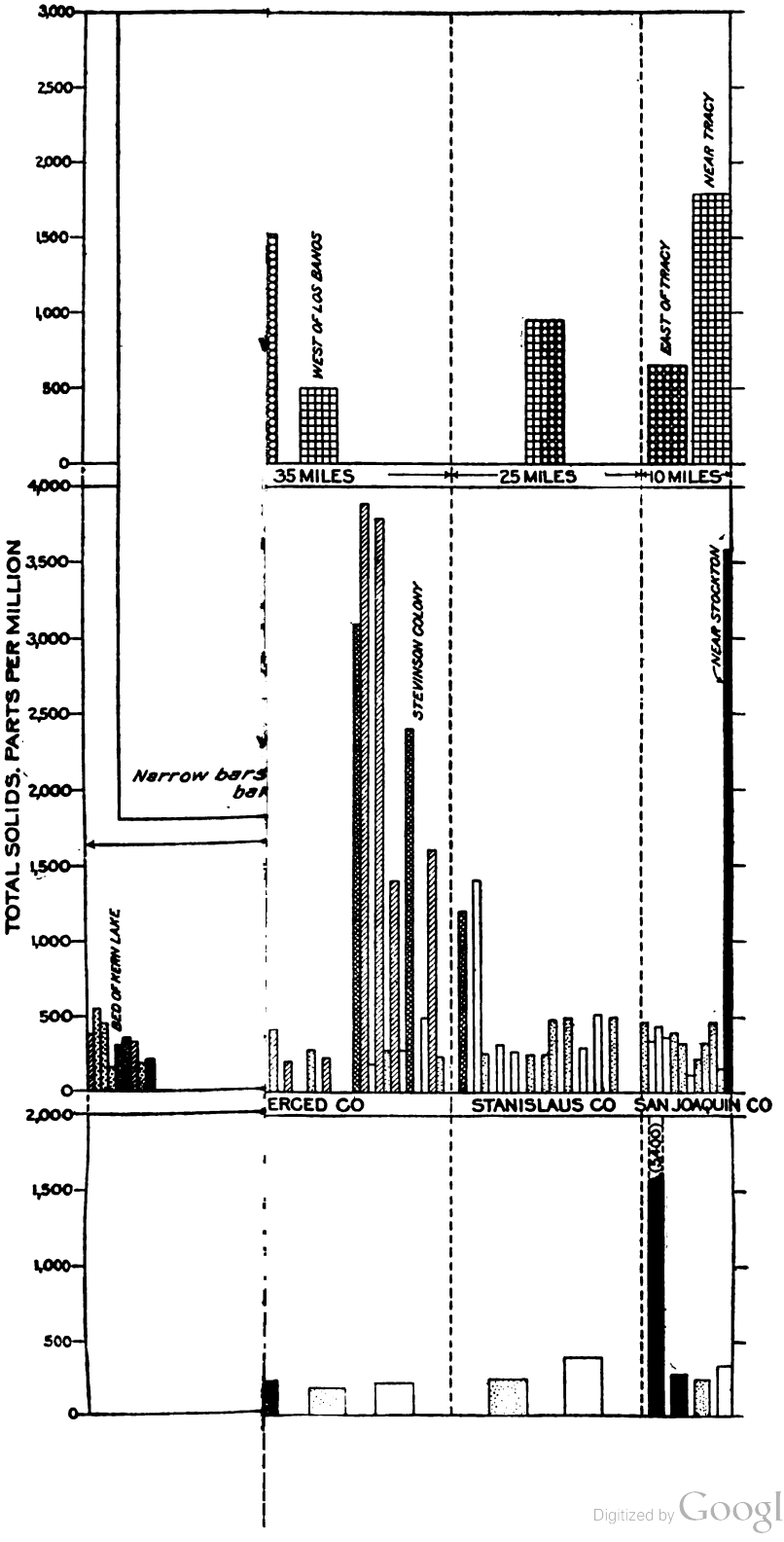

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as much mineral matter; and the waters that were tested from wells more than 1,100 feet deep in San Joaquin County average 5,200 parts per million in mineral content. These data indicate a decided northward increase beginning in Fresno County in the mineral content of the deep waters, a conclusion that is corroborated by the few available tests of deep ground waters in the axis. The 2,250-foot well in sec. 14, T. 18 S., R. 18 E., included among the axial waters, yields poor water, and the 1,200-foot well at French Camp furnishes a supply comparable with the deep waters at Stockton.

OCCLUSION OF SEA WATER.

Though it has been suggested that this increase of solids, representing increase of chloride and alkali, is evidence of the occlusion of sea water within the deep sediments, the composition of the waters makes this improbable. Sea water contains 33,000 to 37,000 parts per million of mineral matter in solution, while the water of a 1,786-foot well at Stockton contains 4,700 parts, that of a 2,500-foot well at Stockton 7,489 parts, and that of the 1,200-foot well at French Camp only 3,000 parts. Besides this striking difference in concentration the figures in table 27 prove that the composition of the mineral matter is also entirely different from that of sea water. The analysis of water from the 2,500-foot gas well at Stockton has been selected for comparison because it is the strongest water and because as much as possible of the upper fresh waters has been excluded. Even if the deep water had been diluted through a leaky casing the composition of it could not have been so radically changed from that of sea water.

TABLE 27.—*Comparison of the composition of water from a 2,500-foot well at Stockton with that of sea water.*

[Percentage of anhydrous residue.]

Constituents.	Well.[a]	Ocean.[b]
Silica (SiO_2)	0.72	.....
Calcium (Ca)	10.72	1.20
Magnesium (Mg)	3.24	3.72
Sodium and potassium (Na+K)	22.40	31.70
Carbonate radicle (CO_3)	.64	.21
Sulphate radicle (SO_4)	.00	7.69
Chlorine (Cl)	62.28	55.29
Salinity (parts per million)	7,489	33,010 to 37,370

[a] Silica not determined. Estimated for purposes of computation as 50 parts. Analysis by F. M. Eaton, Sept. 19, 1910.

[b] Average of analyses by Dittmar; quoted by Clarke, F. W., The data of geochemistry: U. S. Geol. Survey Bull. 616, p. 123, 1916. Minor ingredients omitted.

These waters are similar only in that they are both strong solutions of sodium chloride. The ratio (1 to 3.3) between the amounts of calcium and magnesium in the well water is that of ordinary ground water and is the reverse of that in sea water (3.1 to 1). This fundamental difference and the undoubted absence of any appreciable

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quantity of sulphate in the well waters, whereas the residue of ocean water contains nearly 8 per cent of sulphate, makes it entirely improbable that the saline character of the deep-seated supplies is due to the retention of ocean water within the valley sediments. It is more reasonable to believe that the salt represents an accumulation derived from the silts through which the water has very slowly passed.

SHALLOW WATERS.

Waters from wells 400 to 1,100 feet deep in the axis of the valley increase from south to north in mineral content, but on the east side waters from wells of similar depth are slightly mineralized and are much alike in composition irrespective of their position. Shallower waters show great local diversity of composition in the east side and in the axis. No regular relation holds for supplies of this class, and their quality is predictable only from local tests.

On the west side local conditions determine the quality of ground waters, in which no regular increase of mineral content from south to north is apparent. The mineral content of waters on the west side is highest in Fresno County, and it decreases northward, rising somewhat near the foothills in San Joaquin County. The total solids of ground waters near the west shore of Tulare Lake are less than those of supplies in Fresno County, but it is unknown whether that condition prevails in the west side of Kern County.

RELATION OF DEPTH TO MINERAL CONTENT.

It is a fairly prevalent belief that the deeper a well goes the greater is the mineral content of its water. Yet a little thought establishes the unreasonableness of such general assumption, and a cursory review of analytical data is sufficient to prove the fallacy of it. The mineral content of a ground water depends primarily on the kind of rock with which it comes into contact, and its chemical composition at any stage in its progress tells the main facts of its history. Pressure, temperature, and duration of contact, the physical structure of the rocks, and the nature of substances previously dissolved in the water influence the extent and the manner in which minerals are acted on by the solvent, but the effect of these conditions is subordinate to that of the chemical composition of the rocks themselves, which is the chief determining factor of the mineral content of ground water. It is therefore not at all rare to find deep waters better than shallow ones. Many wells 1,000 to 3,000 feet deep in sedimentary rocks penetrate strata yielding widely different kinds of water, but without any relation to depth except in so far as depth has reference to the character of the rocks that contain the supplies. Indeed, these facts are so nearly self-evident that it would be needless to state them

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if belief in a general relation between depth and quality were not so frequently expressed.

Differences in the quality of water from various depths can be detected in almost every locality in San Joaquin Valley, but they are not regular and can not be widely generalized. Nearly all the best waters on the east side are produced by wells 200 to 1,000 feet deep. They are generally good for irrigation, fair for boiler use, and entirely acceptable for domestic supply. On the east side it is not unusual to find the water from wells 10 to 30 feet deep much harder than that from deeper wells. Similar greater mineral content of shallow waters from glacial deposits derived from calcareous formations in the Central States has been noticed, and it is probably due to more rapid mechanical disintegration of the layers nearest the surface and to greater abundance of solvents like carbon dioxide in the upper waters.

Geographical location has more influence than depth on the mineral content of well waters on the west side a few miles from the river, for the differences of composition among the waters at various depths are not so great proportionately as on the east side.

The relations between depth and quality are more uncertain along the axis than in any other part of the valley. For example, wells 30 to 100 feet deep in Stevinson Colony yield fresh water of moderate mineral content, but wells more than 300 feet deep yield undesirable salt water. On the other hand, water from wells less than 100 feet deep near Tulare Lake is highly alkaline, and the best supplies are obtained from wells 800 to 2,000 feet deep.

QUALITY FOR IRRIGATION.

EAST-SIDE WATERS.

Almost no trouble from poor quality of ground waters for irrigation has been reported throughout the east side of the valley, and available analyses amply confirm the results of experience besides indicating more territory into which this application may be extended. Wells generally throughout the east side yield water that is good or fair for irrigation—the supplies may be used year after year with only moderate care to prevent alkali accumulation due to the mineral constituents of the waters. This statement should be supplemented by the warning that the soil in many sections already contains enough alkali to interfere with cultivation under ordinary conditions and that water of any quality, no matter how good, can not assist in producing full crops on such areas until the excess of sodium salts in the ground has been removed by drainage or by some other means. It is therefore important to note that statements regarding the quality of waters for irrigation refer only to the action of the mineral ingredients of the waters in reducing or increasing the

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mineral content of the soil solution. On the other hand, notes of the actual effect of the waters on crops involve all growing conditions, such as the nature of the ground, the care given the crops, and other features; consequently a statement that crops have not flourished after having been irrigated by a certain water does not necessarily imply that the mineral constituents of the water did the damage.

The best waters for irrigation on the east side are furnished by wells 200 to 1,000 feet deep, though a large number of shallow wells also are utilized. Within the artesian area south of Kings River water from wells as deep as 1,600 to 2,000 feet is satisfactory and has been used on crops. North of Fresno water from wells more than 1,000 feet deep is poor, and near the northern end especially it is unfit for irrigation. Four waters that were tested from wells 1,200 to 2,500 feet deep in and around Stockton are bad because they are strongly saline. Tests of the deep wells at the waterworks, a 1,162-foot well, and a 1,010-foot well near Stockton indicate that sodium replaces calcium as the predominant base at a depth of about 900 feet and consequently that the ground waters become progressively poorer from that depth down to about 1,200 feet where the salty supplies are struck. So few deep wells could be tested south of San Joaquin County that it is uncertain how far southward this condition extends, but it seems reasonable to assume that it is general over the east side between Stockton and Fresno.

WEST-SIDE WATERS.

Wells are being pumped for irrigation at several places on the west side of the valley, and continued settlement of that region will undoubtedly result in greatly increased use. The ground waters of the west side, being much more highly mineralized than those of the east side, are poorer for irrigation. Few of those that were tested, however, are so bad that they are absolutely unfit for use, a fact all the more important because the absence of perennial streams and other surface supplies capable of being stored on the mountain slopes makes the adoption of ground supplies a necessary feature of utilizing the lands. Though the mineral content of the waters is high, the principal ingredients away from the axis are calcium, magnesium, and sulphate, the toxic alkalies being relatively low. Water of this calcium sulphate type can be applied to land without injury at far greater concentrations than are allowable for sodium waters; indeed, calcium sulphate in the form of gypsum or "land plaster" is often spread on fields to neutralize the deleterious effect of black alkali.

Several tracts in western Fresno County now being irrigated by well water have not been under cultivation long enough fully to demonstrate the value of the waters, but sufficient time has elapsed

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to make it apparent that selected crops under proper care can be raised. The results at the pumping stations of the Pacific Coast Oil Co., where lawns, fruit trees, and garden truck have been irrigated for several years, also give favorable testimony as to the feasibility of utilizing the west-side waters.

AXIAL WATERS.

Calcium and magnesium are the predominant bases in the typical waters of both sides of the valley, but they gradually become subordinate toward the axis, where the alkalies, sodium, and potassium, occur in greater quantity. This alteration takes place more or less generally within the limits of the artesian area, and it is practically complete within the boundaries indicated by lines A'A' and B'B' of Plate II. Because of this alteration the axial waters are least desirable for irrigation, and further development of irrigation on both sides of the valley, with resultant increase of the more readily soluble constituents in the ground supplies, will probably make the axial waters still poorer and will also cause greater accumulation of alkali there in the soil. This probability that the axis will eventually become the sewer for the rest of the valley suggests that safe cultivation of the ground there will necessitate the construction of dikes and underdrains for the purpose of removing the alkali and preventing undue rise of the ground-water level. Water from artesian wells 1,400 to 2,000 feet deep close to the present shore of Tulare Lake is being successfully used for irrigating alfalfa, grain, and other crops, but many wells less than 400 feet deep in that region yield unsatisfactory supplies. Tests of water from wells 300 to 600 feet deep in Stevinson Colony indicate that the water is bad for irrigation, and attempts to use it in crops have been unsuccessful. It is understood that a similar failure followed use of some of the deep waters in Jamesan Colony.

RESULTS OF USING GROUND WATERS.

The character, mineral content, and classification of some supplies that have been applied to crops in San Joaquin Valley are presented in Table 28 in order to give a general idea of the kinds of water that are available. The tests have been grouped for convenience under three headings. Reference may be made to the tables of assays (pp. 182–294) for information regarding the value of other local waters for irrigation. The quality for irrigation has been computed from the analytical data and it is followed by a statement regarding the result of applying the waters to crops. Where no information is given other than that certain cultures have been irrigated it may be understood that those cultures have been irrigated for several consecutive years without apparent ill effect due to the quality of the water.

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TABLE 28.—*Types of ground water in San Joaquin Valley and their value for irrigation.*

East side.

Total solids (parts per million).	Chemical character.	Quality for irrigation.	Results of use in irrigation.
160	$Ca-CO_3$....	Good....	Irrigates alfalfa and sorghum.
160	...do.....	...do.....	Irrigates alfalfa.
180	...do.....	...do.....	Irrigates grapes.
190	...do.....	...do.....	Irrigates peaches.
190	...do.....	...do.....	Irrigates grapes and alfalfa.
190	...do.....	...do.....	Irrigates grapes.
200	...do.....	...do.....	Has irrigated garden several years.
200	...do.....	...do.....	Irrigates garden.
210	...do.....	...do.....	Do.
230	...do.....	...do.....	Irrigates olive trees.
250	...do.....	...do.....	Irrigates alfalfa.
258	...do.....	...do.....	Irrigates orange trees.
260	...do.....	...do.....	Has irrigated oranges 6 years.
400	...do.....	...do.....	Irrigates garden.
140	$Na-CO_3$....	...do.....	Irrigates alfalfa, garden, and fruit trees.
150	...do.....	...do.....	Has irrigated grapes, alfalfa, and garden several years.
150	...do.....	...do.....	Irrigates alfalfa.
160	...do.....	Fair.....	Used several years on alfalfa.
170	...do.....	...do.....	Successfully used on grapes and alfalfa.
170	...do.....	...do.....	Successfully used on alfalfa and fruit trees.
200	...do.....	...do.....	Irrigates alfalfa.
220	...do.....	...do.....	Used on garden truck 30 years without trouble.
230	...do.....	...do.....	Irrigates alfalfa.
300	...do.....	...do.....	Irrigates fig, peach, and other fruit trees.
370	...do.....	...do.....	Used generally in city for lawns and gardens.
390	...do.....	...do.....	Do.
2,000	Na-Cl.....	Bad.....	Destructive to crops.

Axis.

372	$Ca-CO_3$....	Good....	Irrigates orange trees.
130	$Na-CO_3$....	...do.....	Irrigates lawn and garden.
130	...do.....	...do.....	Has irrigated alfalfa, cabbages, and garden truck 18 years.
130	...do.....	...do.....	Irrigates lawn, garden, and trees.
140	...do.....	...do.....	Irrigates grain and alfalfa.
140	...do.....	...do.....	Irrigates alfalfa.
150	...do.....	...do.....	Do.
170	...do.....	...do.....	Used several years on alfalfa.
190	...do.....	...do.....	Irrigates orchard and garden.
190	...do.....	Fair.....	Used 3 years on alfalfa, grapes, and peaches.
200	...do.....	Good....	Irrigates garden and fruit trees.
200	...do.....	Fair.....	Irrigates alfalfa.
210	...do.....	...do.....	Used on alfalfa several years.
218	...do.....	Good....	Irrigates melons, grapes, and garden truck.
220	...do.....	Fair.....	Irrigates alfalfa, grapes, and garden truck.
220	...do.....	...do.....	Irrigates asparagus.
260	...do.....	...do.....	Irrigates alfalfa.
700	...do.....	Poor....	Used on alfalfa, garden, and orchard to some extent in 2 years without bad effect.
1,200	...do.....	Fair.....	Irrigates garden.
2,300	...do.....	Bad.....	Kills grass around well.
600	$Na-SO_4$....	Fair.....	Has irrigated vegetables and berries 8 years.
980	...do.....	Poor.....	Used 1 year on garden.
300	Na-Cl.....	Fair.....	Irrigates alfalfa.
310	...do.....	...do.....	Irrigates wheat and alfalfa.
670	...do.....	Poor....	Used successfully on alfalfa.
810	...do.....	...do.....	Said to kill vegetation.
1,210	...do.....	...do.....	Has been used on grain and alfalfa. Not now used.
1,600	...do.....	...do.....	Garden truck did not grow well when irrigated with water. Tomatoes grew smaller each year.
2,400	...do.....	Bad.....	Tried unsuccessfully on crops.

West side.

410	$Ca-CO_3$....	Good....	Irrigates lawn and trees.
620	$Na-SO_4$....	...do.....	Irrigates garden and small fruit trees.
950	...do.....	Fair.....	Irrigates lawn and trees.
1,600	...do.....	...do.....	Has irrigated wheat and barley 2 years.
1,200	$Ca-SO_4$....	Good....	Irrigates lawn and trees.
1,500	...do.....	...do.....	Has irrigated alfalfa, cotton, and garden truck successfully for 1 year.
2,400	...do.....	Fair.....	Has irrigated barley 1 year.

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The data in Table 28 prove that the nature as well as the quality of the dissolved matter has much to do with its effect. Waters containing as much as 1,200 to 2,400 parts per million of total solids, the chief constituents of which are calcium and sulphate, have been successfully applied to cultures. This quantity of mineral matter is greater than the maximum considered allowable in California under the ordinary practice by Hilgard,[1] who evidently has alkali waters especially in mind. Continued use of these stronger waters will undoubtedly involve careful selection of crops and installation of underdrainage to prevent excessive accumulation of alkali. Many sodium carbonate or black alkali waters are being used without apparent trouble near the center line of the valley, but they are all rather low in mineral constituents, total solids being 140 to 400 in the best waters and exceeding 800 parts per million in only a few. It is fortunate that the deep waters east of Tulare Lake are low in mineral matter, as they belong to the sodium carbonate class. The calcium carbonate waters, ranging in this valley usually from 150 to 400 parts per million of solids, can be used without any trouble, and they are classed as good or fair for general irrigation.

EFFECT OF COLD WATER.

The slow development sometimes reported regarding cultures irrigated with ground water on the east side may be caused by the low temperature of the water when it reaches the feeding rootlets, a condition that is undesirable particularly during early stages of growth. Cold water has its greatest retarding effect when it is applied by flooding or by "basin irrigating," as the method of running water into shallow pools around the trunks of bushes and trees is known. When the water is applied through furrows it has opportunity to become warm before it reaches the delicate roots, and the harmful consequences of low temperature are thus avoided. The same result can be obtained by storing the supplies in reservoirs, though this occasions some loss by evaporation. It is customary in many districts to pump into reservoirs during the day and to distribute the supply during the night, when the loss by evaporation is less and more water can therefore be absorbed by the ground, which also does not bake so badly on the surface after the downward percolation. The chill is taken from the water during this storage and subsequent damage is obviated.

[1] Hilgard, E. W., Soils, p. 248, The Macmillan Co., New York, 1906.

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QUALITY FOR INDUSTRIAL USE.

INDUSTRIAL DEVELOPMENT.

Two transcontinental lines traverse the valley from end to end, comprising, with their branches and some shorter systems, about 1,400 miles of track, along which the consumption of water by locomotives is over 3,000,000 gallons a day. Most of this mileage is on the east side of the valley, where the best waters for boiler use are found, but two or three lines already enter the west side, and agricultural development there will soon necessitate more extensive transportation facilities. The numerous wineries in the vineyard districts, particularly around Stockton and Fresno, use large quantities of water for steam making and for washing vats and bins. Ice factories are operated in the larger cities, where laundries and breweries also are important consumers.

EAST-SIDE WATERS.

The ground waters of the east side are generally suitable for boiler use without purification. As they belong mostly to the calcium carbonate type and contain practically no sulphate and rarely much chloride, they are not likely to foam or to be corrosive. The quantity of scale-forming ingredients ranges from 90 to 300 and of foaming ingredients from practically nothing to 250 parts per million. The supplies are generally good or fair for boiler use, form a soft scale, and do not require boiler compounds.

Table 29 contains a summary of tests of east-side industrial supplies particularly in reference to boiler use. The softest supplies supplies almost everywhere on the east side are obtained from wells 200 to 1,000 feet deep. Water from many wells less than 50 or 60 feet deep contains more scale-forming matter than that from deeper wells, and it is therefore less desirable for industrial use. This condition may be demonstrated by comparison of analyses at Stockton, Merced, Fresno, and Tulare, and, though it is not invariable, it is near enough so to make it worth while to investigate the quality of deeper waters before extensive industrial development is undertaken in unexplored localities. Wells more than 1,200 feet deep at Stockton, French Camp, and Madera yield salt water unfit for boiler use, and all wells of that or greater depth on the east side as far south as Fresno will probably yield bad water. Wells of the same depth in Tulare County, however, yield supplies that are very low in scale-forming ingredients, noncorrosive, and low enough in foaming constituents to be classed as good or fair for boiler use. Some ground waters on the east side, more commonly shallow ones, contain enough iron to make them

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industrially undesirable. This type of water is avoidable, however, and water of acceptable quality may be obtained nearly everywhere on the east side.

WEST-SIDE WATERS.

The west-side supplies are very hard calcium sulphate waters. They form hard refractory scale in boilers, and many of them are corrosive, and consequently as a class they are undesirable for boiler use. The most highly mineralized sources were found in the west side of Fresno County and in the south part of western Merced County. It is understood that very bad boiler waters also are encountered west of Buttonwillow in Kern County. Few of the waters used in boilers on the west side belong in the calcium sulphate class, for most of them are near enough to the axis to be predominant in alkalies. In order to avoid confusion, however, those from wells in the territory west of the boundary indicated by A′A′ in Plate II have been entered in Table 29 as west-side waters.

The quantity and hardness of the scale produced generally by west-side waters are such that softening is necessary before introduction of the waters into boilers. The Southern Pacific Co. treats 300,000 to 350,000 gallons of water daily at Tracy and about 30,000 gallons at Westley, and avoids the use of ground water at Los Banos, Firebaugh, and Mendota by pumping from San Joaquin River. The water at Tracy is treated with lime and soda ash in a cold-water softening plant, about two-thirds of the incrusting matter being removed. The supply at Westley, fairly high in incrustants and in foaming constituents, is softened by means of lime, the sludge being dumped on the ground near the tanks. The supply at the ice factory of the Newman Light and Power Co. at Newman gives a large amount of hard scale even after having been passed through an open heater with a filtering attachment. Though the railroad supply at that place is much lower in incrustants it contains nearly as great quantity of foaming ingredients, and the city water is like the railroad supply. Experience at the pumping stations along the pipe line of the Pacific Coast Oil Co. is valuable not only in showing the normally poor quality of the west-side waters for boiler use but also in demonstrating how much can be done to improve them by scientific treatment. The pipe line, after entering the west side a few miles north of Tulare Lake, traverses it from south to north at a distance of 5 to 10 miles from the axis. Most of the boiler supplies along the line are of sodium sulphate character—that is, sodium and sulphate are the chief ingredients, but the waters also contain much calcium and magnesium. This makes them capable of forming considerable hard scale and of foaming when they are concentrated; altogether they

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range from poor to very bad for boiler use in the raw state. It is general practice at the pumping stations to remove a large part of the incrusting matter by treating the supplies with soda ash in open heaters. The tendency to foam is increased in proportion to the quantity of soda ash added, but trouble from that source is obviated by frequent blowing off. The boilers are cleaned regularly every three weeks or oftener, and this attention coupled with the preliminary treatment makes it possible to utilize the waters without trouble or danger. The waters still farther west, however, are generally much higher in incrustants, and many of them are so hard that they could not be rendered fit for use by any treatment except distillation.

AXIAL WATERS.

Excellent supplies for boilers can be obtained from deep wells between Tulare Lake and the city of Tulare in Kings and Tulare counties. Several waters near Corcoran and Angiola produce almost no scale and can be strongly concentrated without trouble from foaming or corrosion.

RESULTS OF USING GROUND WATERS.

The more important facts in reference to the industrial supplies of the valley are summarized in Table 29. More complete details of the analyses can be obtained from the analytical tables (pp. 182-294). The analyses have been grouped for convenience under three headings and by chemical character.

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TABLE 29.—*Some industrial water supplies in San Joaquin Valley.*

[Parts per million except as otherwise designated.]

East side.

Scale-forming ingredients (s).	Foaming ingredients (f).	Probability of corrosion (c).[a]	Character of water.	Quality for boilers.	Remarks.
140	10	N. C.	$Ca\text{-}CO_3$....	Fair.....	Used in wine making and in boilers. Wash boilers once a week and get soft sludge. No compound used.
90	40	N. C.	...do.....	Good.....	Used in boilers.
115	40	N. C.	...do.....	Fair.....	Used in beer making and in boilers. Some compound used.
130	40	N. C.	...do.....	...do.....	Used in wine making and in boilers. Clean boilers once in 3 months. A little sludge removed. Blow one gage in 24 hours. Use skimmer. No compound used.
135	50	N. C.	...do.....	...do.....	Locomotive supply.
150	40	N. C.	...do.....	Good.....	Boiler supply. Clean boilers once a week, getting 7 to 8 pounds hard scale and some sludge No compound used.
160	20	N. C.	...do.....	Fair.....	Distilled for ice making. Little sludge in boilers. Practically no scale on atmospheric condensers in 4 months.
125	80	N. C.	...do.....	...do.....	Locomotive supply.
155	60	?	...do.....	...do.....	Do.
100	10	?	...do.....	Good.....	Distilled for ice making. Little sludge.
190	90	?	...do.....	Fair.....	Locomotive supply.
300	30	?	...do.....	Poor.....	Do.
200	140	?	$Ca\text{-}SO_4$....	Fair.....	Do.
300	160	?	...do.....	Poor.....	Do.
60	80	N. C.	$Na\text{-}CO_3$...	Good.....	Do.
100	80	N. C.	...do.....	Fair.....	Boiler supply. Clean every 2 weeks. Eggshell scale; no corrosion; no compound used; blow one-half gage two or three times each shift.
105	100	N. C.	...do.....	...do.....	Locomotive supply.
40	250	N. C.	Na-Cl.....	...do.....	Do.

Axis.

70	80	N. C.	$Na\text{-}CO_3$...	Good.....	Boiler supply. Practically no scale. No treatment; no corrosion. Blow once in 24 hours.
70	80	N. C.	...do.....	...do.....	Boiler supply. Cochrane heater. No chemicals. Practically no scale.
70	180	N. C.	...do.....	Fair.....	Used in 1,250 H. P. boilers. No scale; no pitting.
50	70	N. C.	Na-Cl.....	Good.....	Boiler supply. No trouble; no treatment.

West side.

280	90	?	$Ca\text{-}CO_3$....	Poor.....	Boiler supply. Use soda ash and Cochrane heater. Boilers cleaned every 3 weeks. Blow 2 gages every 12 hours.
700	270	C.	$Ca\text{-}SO_4$....	Very bad.	Boiler supply. Use soda ash and Cochrane heater.
400	350	?	$Na\text{-}SO_4$....	Bad.....	Boiler supply. Boilers cleaned once a month. Scale hard, brittle, about $\frac{1}{8}$ inch thick. Blow 1 gage every 24 hours. Soda treating plant being installed.
250	220	?	...do.....	Poor.....	Locomotive supply. Cold water softener with lime and soda ash used.
260	840	?	...do.....	Very bad..	Boiler supply. Use soda ash and Cochrane heater. Clean every 18 days. Get 60 to 70 pounds eggshell scale.
125	1,000	N. C.	...do.....	...do.....	Boiler supply. Use soda ash and Cochrane heater. Scale thin, but hard and tough.
230	790	N. C.	...do.....	...do.....	Boiler supply. Treated with soda ash.
160	380	N. C.	...do.....	Bad.....	Boiler supply. Use soda ash and Cochrane heater. Clean every 3 weeks. Blow once a day.
105	500	N. C.	...do.....	Very bad..	Boiler supply. Use soda ash and Cochrane heater. Clean once in 3 weeks. Blow twice in 24 hours.
500	650	?	Na-Cl.....	...do.....	Distilled for ice making. Open heater and compound. Large amount of hard scale.

[a] N. C.=Noncorrosive; C=corrosive; ?=corrosion uncertain or doubtful.

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QUALITY FOR DOMESTIC USE.

DEPTH AND POSITION OF POOR SUPPLIES.

Wells more than 1,200 feet deep in and near Stockton yield salt water unsuitable for domestic use, and though the available information indicates that the salinity decreases southward all wells 1,200 feet or more in depth as far south as Fresno probably yield salty water. Though some shallower supplies on the east side of the valley are moderately hard they are not excessively so, and they are generally acceptable for domestic use.

Water fit to drink can not be obtained from wells close to the foothills in the southwest part of Kern County and at some places in western Fresno County. The highly gypsiferous waters of western Fresno County can not be used for cooking vegetables and they are nauseating to some persons. With the exception of these areas, however, potable ground water can be obtained from wells throughout the west side. They are, as a rule, very hard, and the traveler who is not accustomed to drinking alkali water can readily notice the distinct taste of the supplies west of San Joaquin River. They are not injurious, however, except in the localities just mentioned, and many of the strongly mineralized ones have been used without harm for several years.

All the artesian waters north of Lemoore, except those containing enough chloride to be salty, are suitable for domestic use. The location of the chloride-bearing waters and the extent of the areas likely to yield such supplies are discussed on pages 117–119. Water from some wells less than 300 feet deep close to Tulare Lake is too strongly impregnated with black alkali to be potable. A few waters just south of Lemoore are highly colored and have a peculiar taste, probably because of percolation through buried peat or other vegetable matter. The deeper supplies around Tulare Lake are exceptionally soft and low in all mineral ingredients and they are very good for domestic use.

POSSIBILITY OF POLLUTION.

The close-grained texture of the silt deposits in San Joaquin Valley, the consequent slow movement of the ground waters, and the general practice of boring wells and casing them form effectual safeguards against pollution by surface drainage or seepage from privies and cesspools a reasonable distance away. Dug wells, so often exposed to contamination, form a small proportion of the domestic supplies because of the uncertainty of obtaining sufficient water at the shallow depths to which such wells can be sunk. If bored wells are constructed with care to insure tight casings to a depth of 40 or 50 feet and if the collection of stagnant water or filth around the top of the casing is prevented, there is little danger of pollution.

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MUNICIPAL SUPPLIES.

Cities on the west side near San Joaquin River could avoid troubles incident to the use of hard ground water and could more readily attract prospective manufacturers by drawing from San Joaquin River and its eastern tributaries. Such surface supplies would, of course, have to be filtered, for the streams are subject to pollution by general infiltration, some sewage, and drainage from irrigated lands, but purification would be comparatively simple, and the resulting water would be clear, colorless, and tasteless and extremely low in alkalies and hardness.

Almost all the cities of the valley are supplied with ground water. The composition of the supplies of which analyses are available is given in Table 30.

TABLE 30.—*Chemical composition of some municipal water supplies in San Joaquin Valley.*

[Parts per million except as otherwise designated.]

City.	County.	Depth of well (feet).	Silica (SiO_2).	Iron (Fe).	Calcium (Ca).	Magnesium (Mg).	Sodium and potassium (Na+K).	Carbonate radicle (CO_3).	Bicarbonate radicle (HCO_3).
Alpaugh	Tulare	2,000	.....	.....	.....	.....	.....	Tr.	266
Corcoran	Kings	1,000	.....	.....	.....	.....	.....	9	99
Dinuba	Tulare	278	.....	.....	.....	.....	.....	0	164
Exeter	....do	100	[b] 39	.....	26	9	32	0	144
Lodi	San Joaquin	.....	[b] 60	.....	28	11	26	0	130
Mendota	Fresno	640	.....	.....	.....	.....	.....	Tr.	147
Modesto	Stanislaus	.....	[b] 50	.....	38	10	63	0	110
Newman	....do	396 398	.....	0.40	66	37	[a] 238	0	189
Oakdale	....do	.....	[b] 30	.....	27	12	13	0	120
Portersville	Tulare	200	.....	.....	.....	.....	.....	0	200
Stockton	San Joaquin	[c]	.....	.12	17	7.0	[a] 86	0	205
Do	....do	[d]	[b] 48	.....	23	11	84	0	242
Do	....do	[e]	57	.03	6.1	7.2	89	0	210
Tulare	Tulare	[f]	[b] 16	.....	14	1	24	0	90
Do	....do	800	.....	.25	29	4.0	[a] 18	0	122

City.	Sulphate radicle (SO_4).	Chlorine (Cl).	Total hardness as $CaCO_3$.	Total solids.	Chemical character.	Analyst.	Date.
Alpaugh	5	180	154	[a] 560	$Na-Cl$	R. B. Dole	Nov. 25, 1910
Corcoran	Tr.	15	29	[a] 180	$Na-CO_3$	....do	Nov. 22, 1910
Dinuba	Tr.	40	148	[a] 260	$Ca-CO_3$	....do	Nov. 18, 1910
Exeter	11	27	[a] 100	215	....do	Southern Pacific Co	Dec. 29, 1904
Lodi	7	36	[a] 115	236	....do	....do	May 4, 1908
Mendota	430	75	83	[a] 910	$Na-SO_4$	R. B. Dole	Nov. 1, 1910
Modesto	3	127	[a] 135	344	$Na-Cl$	Southern Pacific Co	July —, 1900
Newman	125	389	[a] 310	1,016	....do	F. M. Eaton	Oct. 13, 1910
Oakdale	14	20	[a] 115	175	$Ca-CO_3$	Southern Pacific Co	Oct. —, 1900
Portersville	Tr.	20	160	[a] 250	....do	R. B. Dole	Nov. 21, 1910
Stockton	0	64	[a] 71	350	$Na-CO_3$	F. M. Eaton	Sept. 18, 1910
Do	5	59	[a] 105	349	....do	D. B. Bisbee	Dec. 3, 1904
Do	7.1	35	[a] 45	306	....do	Walton Van Winkle	Oct. 1, 1910
Tulare	3	8	[a] 40	111	....do	Southern Pacific Co	Apr. 2, 1902
Do	14	9.0	[a] 90	174	$Ca-CO_3$	F. M. Eaton	Nov. 14, 1910

[a] Computed.
[b] Including oxides of iron and aluminum.
[c] Eleven wells at main pumping station 200 to 1,100 feet deep.
[d] Fourteen wells 800 to 1,000 feet deep; water between 200 and 1,000 feet.
[e] Four wells at electric pumping station, Monroe and Poplar streets, 665 to 975 feet deep.
[f] Depth not given; uncertain whether this is from 400 or 800 foot wells.

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The city supply of Bakersfield is taken from shallow wells near Kern River. Madera, Selma, and Visalia also are supplied from wells. Water from Merced River is used in the city of Merced.[1] No analyses of the city supply of Fresno, which is procured from deep wells, are available, but other wells in Fresno and vicinity yield soft or moderately hard calcium carbonate water, clear, tasteless, and entirely acceptable in reference to its mineral content for domestic use. The municipal supply of Los Banos is taken (1910) from an irrigation ditch within the city limits. The water is passed through successive beds of coarse gravel, fine gravel, and charcoal at an excessive rate that precludes proper purification.

MISCELLANEOUS ANALYSES.

ANALYSES BY THE CALIFORNIA EXPERIMENT STATION.

Table 31 has been compiled from reports of the Agricultural Experiment Station of the University of California for 1897–8, 1898–1901 (Part II), 1901–3, and 1903–4, and from "Alkali lands, irrigation, and drainage in their mutual relations," by E. W. Hilgard, an appendix to the report for 1890. The analyses were reported in such form that it is impracticable to resolve them into ionic form for incorporation in other tables of analyses, and they are therefore published in original form, except that the figures have been converted from grains per United States gallon into parts per million. The classification of the waters for irrigation is that reported by the laboratory, and it is not based on the method of interpretation employed by the writer.

As nearly all the examinations are of miscellaneous samples forwarded to the laboratory by persons residing in the valley, data regarding the location of the wells and their depths are necessarily incomplete. It should be understood, therefore, that the first two columns give the name and address of the sender, which do not always coincide with the name of the owner of the well and its location. For example, seven analyses of water from Fresno and six from Hanford are reported, but evidently not all are from wells within the limits of these two cities.

The results of nearly all these examinations accord with the writer's statements regarding the quality of ground waters in the valley. The amount of sulphate, however, represented by the alkaline sulphates reported in the analysis of water from the 1,315-foot well at St. Agnes Academy, Stockton, disagrees with that reported by several chemists in tests of water from other deep wells in and near that city. The discrepancy is doubtless explainable by mixing of samples or error in computation.

[1] Van Winkle, Walton, and Eaton, F. M., The quality of the surface waters of California: U. S. Geol. Survey Water-Supply Paper 237, p. 61, 1910.

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TABLE 31.—*Analyses of ground waters in San Joaquin Valley by the Agricultural Experiment Station of the University of California.*

[Parts per million except as otherwise designated.]

San Joaquin County.

Sender.	Address.	Depth of well (feet).	Total solids.	Portion soluble in water after evaporation.	Portion insoluble in water after evaporation.	Organic and volatile matter.	Composition of insoluble portion.		Composition of soluble portion.			Quality for irrigation.
							Silica (SiO_2).	Calcium carbonate ($CaCO_3$), magnesium carbonate ($MgCO_3$), calcium sulphate ($CaSO_4$).	Alkaline carbonates (Na_2CO_3 + K_2CO_3).	Alkaline chlorides (NaCl + KCl).	Alkaline sulphates (Na_2SO_4 + K_2SO_4).	
R. Hickmott	Bouldin Island	110	1,285	1,005	195	85	35	160	56	928	21	Unsuitable.
Do	do		1,153	898	175	80	45	130	63	730	105	Do.
L. Friedberger	Clements		938	459	215	264	45	170	46	208	205	Doubtful.
Do	do		1,088				Small.	Tr.		High.		Unsuitable.
Do	do	80	299	104	150	45	150		7	11	86	Suitable.
J. D. Ameron	French Camp	200	457	190	192	75	192		7	64	197	Do.
W. H. De Vris	Lodi	20	424					125				Do.
Stockton Asylum	Stockton	1,100	589	436	106	46	54	52	201	235		
Do	do	1,100	626	434	111	80						
Do	do	1,070	819	572	161	86	89	72	153	393	26	
St. Agnes Academy	do	1,315	2,994	2,323	271	400	95	176	53		2,270	
Stockton Water Co.	do	+900	409	197					74	58		
Salmon Estate	French Camp	1,200	4,059	[a] 3,444	134		54	80		2,125		
Hammond & Yardley	Stockton		600	220	270	110	60	210	44	46	130	Suitable.
J. M. Bigger	do		200								High.	Do.
T. B. Bishop	do		1,535	798	507	230	507		254	467	77	Unsuitable.
A. K. Percival	do	2,000	4,800	4,003	258	539	258					Do.

Stanislaus County.

Mrs. J. F. Ecker	Grayson		9,226	6,968	1,647	619	1,647					Unsuitable.
A. Barbour	Newman	100	1,882	1,088	564	230	564		42	752	294	Do.
Do	do	145	1,637	918	519	200	519		32	390	496	Do.
N. O. Hultberg	Turlock		1,015	480	500	35	15	485	128	52	300	Do.
Do	do		1,018	389	509	120	509		17	279	93	Do.

[a] Calcium chloride, 1,183 parts; magnesium chloride, 297 parts.

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TABLE 31.—*Analyses of ground waters in San Joaquin Valley by the Agricultural Experiment Station of the University of California*—Continued.

Sender.	Address.	Depth of well (feet).	Total solids.	Portion soluble in water after evaporation.	Portion insoluble in water after evaporation.	Organic and volatile matter.	Composition of insoluble portion.		Composition of soluble portion.			Quality for irrigation.
							Silica (SiO_2).	Calcium carbonate ($CaCO_3$), magnesium carbonate ($MgCO_3$), calcium sulphate ($CaSO_4$).	Alkaline carbonates ($Na_2CO_3 + K_2CO_3$).	Alkaline chlorides ($NaCl + KCl$).	Alkaline sulphates ($Na_2SO_4 + K_2SO_4$).	
Merced County.												
T. Korslab	Dos Palos		389	164	190	35	190		15	29	120	Suitable.
H. T. Thornton	Los Banos		7,902			Low.	High.			High.	Very high.	Unsuitable.
Madera County.												
A. L. Sayre	Madera	1,200	2,399	1,722	472	205	87	385	34	1,678	10	Unsuitable.
E. C. Foster	....do		179	57	70	45	70		11	6	40	Suitable.
Fresno County.												
Thomas Akin	Fowler	58	190	70	100	20	20	80	21	12	37	Suitable.
W. E. Price	....do		379	100	219	60	219		90	6	4	Do.
N. W. Woody	Fresno		100	20	50	30	30	20			20	Do.
H. C. Eggers	....do		785	495	235	55	108	127	42	153	300	Do.
H. C. McNulty	....do		333	75	218	40	146	72	11	12	52	Do.
W. H. Hodgkins	....do		260	50	165	45	40	125	10	12	28	Do.
C. A. Colmore	....do	80	224	69	115	40	115		7	29	33	Do.
Barton Vineyard Co	....do		208	86	108	14	108		17	6	63	Do.
W. Forsaythe	....do		353	184	120	49	120		21	19	144	Do.
T. Yost	Kingsriver		90									Do.
Geo. E. Bates	....do		449	199	210	40	210		15	11	173	Do.
Isaac Myers	Mendota		8,410	6,688		724		998				Unsuitable.
W. M. Brown	Sec. 2, T. 14 S., R. 14 E.	(a)	1,797	429	1,226	142	51	378	11	274	942	
G. S. Nash	New Idria		2,730	2,130	600		25	575	10	164	1,956	Unsuitable.
Nellie Russell	Pollasky		105									Suitable.

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W. F. Martin	Selma		200							7		Do.
Selma Water Co.	do		101							2		Do.
Do	do		113							6		Do.
John Hastings	5 miles west of Fresno	105	382	122	156	104						Do.
Kings County.												
S. T. Owings	Armona	30	203	28	162	13	162		8	12	8	Suitable.
Mrs. C. W. Sullivan	do	90	523	316	118	75	118		296	6	14	Doubtful.
S. T. Owings	do	550	289	140	92	57	92		21	24	95	Suitable.
M. W. Motheral	Hanford	40	170	35	120	15	25	95	21	3	11	Do.
C. M. Blowers	do	66	140	30	95	15	95		10	6	14	Do.
J. A. Hill	do	110	2,995	923	1,667	200	1,667					Unsuitable.
Do	do	150–200	1,118	819	200	99	200		42	29	748	Suitable.
A. V. Taylor	do	900	289	154	90	45	90		85	45	24	Do.
	do	1,150	260	245	10	5	5	5	127	93	25	
E. Jacobs	Lemoore	442	458	368	15	75			330			
Daniel Rhoads	do	900	462	394	12	55			High.			
R. D. Vandeburg	do	164	499	319	100	80	100		211	6	102	Doubtful.
J. H. Hoskins	South of Tulare Lake		133	85	21	27			Low.	High.	High.	
E. Jacobs	Sec. 15, T. 20 S., R. 20 E	660	370	295	41	34	10	31	284		11	
Tulare County.												
W. H. Wilbur	Angiola	80	5,891	3,905	1,587	399		1,587				Unsuitable.
Do	do	360	3,953	1,967	1,587	399		1,587				Do.
W. T. Rambo	do	16	3,085	1,997	599	489	599					Do.
D. P. Denney	do		1,197	658	429	110	429		278	200	180	Do.
T. Paige	Cross Creek		206	173	33		14	19	153	7	13	
K. A. Linder	Dinuba		210	45	145	20	80	65	11	12	22	Suitable.
	Goshen		165	100	40	25	24	16	74	7	19	
Dr. Pierce	Lindsay		530	190	215	125	75	140	65	47	78	Suitable.
J. H. Williams	Portersville		489	269	130	90	130		69	43	157	Do.
J. W. Williams	do	115	389	279	70	40	40	30	106	46	127	Do.
D. H. Madden	Tulare	220	99	56	26	17	8	18	52		4	
H. Wheeler	do	136	549	484	50	15	15	35	22	116	346	Suitable.
Do	do		661	541	58	62	20	38	22	11	508	Do.
W. H. Wilbur		360	4,005	2,421	1,255	329	1,255		584	1,473	414	Unsuitable.
Do		1,100	4,140	2,520	1,060	560	60	1,000	478	1,348	694	Do.
S. F. Hoover	Tulare		155	110	20	25	10	10	64	23	23	Suitable.
W. B. Cartmill			270	50	190	30	190		21	6	23	Do.
E. M. Dewey	7 miles south of Tulare	309	171	89	62	20	35	27			17	
	10 miles north of Visalia	900	1,498	890	194	414				High.		

[a] Three wells, 380, 414, and 450 feet deep. Analysis reported by owner.

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TABLE 31.—*Analyses of ground waters in San Joaquin Valley by the Agricultural Experiment Station of the University of California*—Continued.

Kern County.

Sender.	Address.	Depth of well (feet).	Total solids.	Portion soluble in water after evaporation.	Portion insoluble in water after evaporation.	Organic and volatile matter.	Composition of insoluble portion.		Composition of soluble portion.			Quality for irrigation.
							Silica (SiO_2).	Calcium carbonate ($CaCO_3$), magnesium carbonate ($MgCO_3$), calcium sulphate ($CaSO_4$).	Alkaline carbonates ($Na_2CO_3 + K_2CO_3$).	Alkaline chlorides ($NaCl + KCl$).	Alkaline sulphates ($Na_2SO_4 + K_2SO_4$).	
J. S. Drury	Bakersfield	.....	4,425	2,895	1,005	525	45	960	21	12	2,862	Unsuitable.
D. E. Josephi	....do	38	4,044	3,308	550	186	65	485	21	255	3,032	Do.
Kern County Land Co.	....do	1,000	9,555	9,183	202	170	27	175	1,755	6,355	1,043	Do.
D. E. Josephi	....do	289	289	104	145	40	20	125	.....	24	80	Suitable.
S. Dickinson	....do	.....	1,495	1,315	180	.....	20	160	22	397	896	Unsuitable.
B. Thomas	Delano	.....	353	120	188	45	34	154	16	39	65	Suitable.
J. M. Thompson	Kern	70	179	130	29	20	29		.....	.....	.....	Do.
Do	....do	.....	211	90	50	71	50		.....	.....	.....	Do.
C. F. Banks	McKittrick	.....	5,789	3,593	1,697	499	.....	1,697	.....	.....	.....	Unsuitable.
L. S. Harman	Rosedale	.....	1,397	419	918	60	918		53	31	285	Do.
	Sec. 33, T. 35 S., R. 23 E.	340	174	86	36	42	.....	.....	.....	.....	High.	

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ANALYSES BY THE RECLAMATION SERVICE.

A few analyses of water from wells in San Joaquin Valley were made by chemists of the Reclamation Service during 1904 and 1905. Though the results have heretofore been published[1] they are included herewith in order that the analytical records may be complete. The analysis of water from the 1,990-foot well at the State Insane Hospital, Stockton, agrees closely with those of water from other very deep wells in the city. The water of the well at Firebaugh is nearest in composition to that of the 532-foot well at Miller pumping station in sec. 22, T. 13 S., R. 14 E. The highly mineralized water from a flowing well reported as being at Tulare is undoubtedly from a well about 200 feet deep west of Angiola. Though the sources of the other samples can not be identified, the analyses of them agree entirely with the statements made in the preceding text.

TABLE 32.—*Analyses of water from wells in San Joaquin Valley by chemists of the United States Reclamation Service.*

[Parts per million.]

Location.	County.	Date.	Carbonate radicle (CO_3).	Bicarbonate radicle (HCO_3).	Chlorine (Cl).	Dissolved solids.
State Insane Hospital, Stockton[a]	San Joaquin	Mar., 1907	0	84	3,620	6,940
SE. ¼ sec. 17, T. 11 S., R. 18 E.	Madera	July, 1905	0	174	85	380
NE. ¼ sec. 11, T. 7 S., R. 12 E.	Merced	do	0	123	14	328
SW. ¼ sec. 23, T. 7 S., R. 13 E.	do	do	7	336	70	584
Tulare[b]	Tulare	Dec., 1905	0	1,630	436	2,110
Portersville	do	do	0	205	2	250
Goshen	do	do	3	82	7	156
Firebaugh	Fresno	do	0	195	225	1,420
Buttonwillow	Kern	do	0	455	35	816
Bakersfield	do	do	0	254	21	358
Dudley	Kings	do	0	241	183	2,090

[a] Depth, 1,990 feet; calcium (Ca), 600; magnesium (Mg), 171; sodium and potassium (Na+K), 1,370; sulphate radicle (SO_4), 8 parts per million.
[b] Flowing well.

FORECASTING QUALITY OF GROUND WATER.

The analyses and assays accompanying the county notes (pp. 177–306) are tabulated by range, township, and section, the locations on the Spanish land grants being inserted in proper order to conform to that arrangement. The locations of the wells from which samples of water were collected are indicated in Plate II (in pocket). The tables show first the amounts of the ingredients determined by analysis, then certain computed amounts necessary to proper understanding of the quality, and lastly classifications indicating the approximate nature of the waters and their general usefulness. The information thus tabulated is so detailed that it is not necessary to describe the waters individually in the text. The formulas that

[1] Stabler, Herman, Some stream waters of the western United States: U. S. Geol. Survey Water-Supply Paper 274, p. 146, 1911.

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have been used in the computations and the ratings by which the waters have been classified are fully described in pages 50–83.

The best way to use this material in forecasting the local quality of water is to study the tabulated analyses in connection with Plates II, III, and V and figure 2. After analyses of the water of wells near the locality under consideration have been compared, sections through the locality should be drawn representing the depth of the wells in relation to the composition of their waters. The deeper a well is the greater the area over which its water may be considered representative, because the deep supplies circulate more slowly than the upper ones and are less affected by rainfall, vegetation, and slope. The general direction of movement of the deep waters is from the foothills toward the axis, gradually changing near the axis to a direction parallel with it. Waters within 20 to 50 feet of the surface are diverted more or less from this course by surface configuration—that is, shallow waters move toward near-by gullies, coulees, or watercourses. The somewhat meager information on the subject indicates that shallow wells in the sandy deltas yield better water than shallow wells in the slight depressions between the deltas, and that shallow wells in land showing alkali patches yield poorer water than those in nonalkali tracts. Several shallow wells in dry stream beds were found to yield less strongly mineralized water than neighboring wells not affected by the stream underflow. These conditions are not invariable, but if they are considered with judgment knowledge of them is helpful in predicting the quality of water in the unexplored areas of the valley.

SUMMARY.

The more important conclusions regarding the quality of water in San Joaquin Valley may be summarized as follows:

The waters of the perennial streams are entirely suitable for irrigation; storage to remove suspended matter renders them acceptable for boiler use, and filtration would purify them for domestic supply.

On the east side between the Sierra and the trough of the valley wells 20 to 1,000 feet deep generally yield calcium carbonate waters, moderate in total solids and in total hardness and distinguishable by their low sulphate content. These waters are suitable for domestic use, good or fair for irrigation, and fair or poor for boiler use. Many of them have been successfully applied to diversified crops for several years. Water from wells less than 50 feet deep is generally poorer than that from slightly deeper wells.

On the west side wells between the Coast Range and the trough of the valley yield hard, gypseous waters high in mineral content

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and especially in sulphate. Nearly all the waters taste of alkali, but they are potable except the most highly concentrated ones close to the foothills. The west-side waters are poorer for irrigation than those of the east side, but few of them are unfit for use if proper care is taken to prevent accumulation of alkali. They contain so much scale-forming matter that they should be softened before use in boilers, and many of them are so strongly mineralized that they can not be economically softened.

In the axis or trough of the valley wells yield waters distinguishable by the predominance of sodium and potassium among the basic radicles. These waters gradually mingle on either side of the valley with those of the east-side and west-side types, and they are locally altered by seepage from both sides of the valley. The ground waters in the axis differ much from each other in concentration and in composition and therefore in their economic value. Nearly all except the salt waters and those from wells less than 300 feet deep in or near the bed of Tulare Lake are potable. Many of those north of Kings River are poor for irrigation and are too high in foaming constituents to be suitable for steaming. The deep artesian waters south of Kings River are good or fair for irrigation and for boiler use.

Borings more than 1,200 feet deep as far south as Fresno County yield strong salt waters unfit for use, but south of that county wells of that or greater depth, yield sodium carbonate waters of low mineral content. Many flowing wells 300 to 800 feet deep in the axis also yield salt water.

The chief reason for the difference of composition between ground waters of the east and the west side is the different character of the sediments through which they pass; the silt brought down from the Sierra was derived from old, difficultly soluble rocks, but that from the Coast Range was derived from more recent metamorphic and sedimentary rocks containing gypsum and other readily soluble constituents. Alkalines predominate in the axial waters because the more readily soluble constituents have become concentrated during the movement of the waters toward the natural drain of the valley.

The very deep waters of the east side and of the axis increase northward in mineral content, but the shallow waters show no such general relation.

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PUMPING TESTS.

By HERMAN STABLER.

NOTES ON THE PLANTS.

During the summer of 1910 pumping tests were made on about 50 irrigation plants in San Joaquin Valley, in connection with other studies of the water supply. In the following pages a description of each plant and test is given, with brief remarks concerning the results shown by the test. The date of installation is given in the heading. The data of chief interest to the irrigator have also been collected in Table 34, in which the various factors in the cost and relative efficiency of the several plants are presented. A summary of the principal points to be observed in order to obtain good service from a pumping plant is also appended.

1. T. R. HILL, LODI, CAL. (1910).

Location.—Lot 7 of the Hogan tract, SW. ¼ sec. 19, T. 3 N., R. 7 E., Mount Diablo base and meridian.

Plant.—6-horsepower Samson distillate engine, 18-inch pulley; belt-connected to a 3½-inch Samson horizontal centrifugal pump with 8-inch pulley, catalogue capacity of 250-300 gallons per minute. Well, bored, 8 inches by 44 feet, uncased; water 8 feet below the surface.

Building cost.—Engine, $235; pump, $85; well, $22; complete plant, $385.

Use in 1910.—Preparation of land and irrigation of young alfalfa. Proposed plan of irrigation provides for the watering of 4 acres of alfalfa eight times.

Test.—The following results were obtained during a two-hour test of the plant on September 25, 1910.

Consumption of distillate, gallons per hour, 0.96.

Water pumped, gallons per minute, 256.

Speed, revolutions per minute: Engine, 310 (marked 325); pump, 686 (catalogue speed, 830).

Head: 6-foot lift; 20-foot suction. Total static head, 26 feet.

Remarks.—The plant is about as small as can be satisfactorily used for irrigating alfalfa but is far larger than a 4 or 5 acre alfalfa tract can support. The owner pays a building cost of $96 per acre, and the cost of plant depreciation, maintenance, and operation amounts to $17 per acre annually. At this rate more than half the value of all the alfalfa that can be raised will be required for the upkeep of the pumping plant and payment of taxes and interest and insurance charges. For the first few years this may not be noted by an owner who makes no allowance for depreciation, but as the plant grows older the problem of renewal must be met.

The efficiency of the plant is low. So far as could be noted without detailed study this is accounted for by the following facts: The engine is larger than is required for the work done and is underspeeded and fed an excess of distillate; the pump is much underspeeded. The owner can not hope to make a living on his small tracts by raising alfalfa. His net revenue could be greatly increased by supplying pumped

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water to adjacent lands and in such case a 4-inch pump could profitably be installed. Care in designing the plant for proper speeds and in operating would add materially to the owner's success.

2. J. C. DUTTON, LODI, CAL. (1906).

Location.—SW. ¼ sec. 31, T. 3 N., R. 7 E., Mount Diablo base and meridian.

Plant.—6-horsepower Samson distillate engine, 22-inch pulley; belt-connected to a 4-inch Samson horizontal centrifugal pump with 8-inch pulley, catalogue capacity 400–450 gallons per minute. Well, bored, 10 inches by 50 to 60 feet, uncased; water 5 to 10 feet below the surface according to season.

Building cost.—Engine, $290; pump, $100; well, $25; complete plant, $495.

Use in 1910.—Irrigation of 3 acres of vineyard watered two or three times, 1 acre of alfalfa, and 1 acre of eucalyptus trees watered once a week or about 12 times in the season.

Test.—The following results were obtained during an hour and a quarter test of the plant on September 26, 1910:

Consumption of distillate, gallons per hour, 1.00

Water pumped, gallons per minute, 380.

Speeds, revolutions per minute: Engine, 248; pump, 666 (catalogue speed, 670).

Head: 6-foot lift; 15-foot suction. Total static head, 21 feet.

Remarks.—The plant is well designed and properly speeded. When tested the batteries were in poor condition and excess of distillate was being used. Poor ignition and relatively low efficiency resulted. The relatively large profits obtainable from a high grade of table grapes probably justify the installation of this plant. The area served is so small, however, that irrigation from it must necessarily be expensive. To provide for economical irrigation by means of this plant an area 10 to 15 times as great should be served with water.

3. J. C. DUTTON, LODI, CAL. (1906).

Location.—SW. ¼ sec. 31, T. 3 N., R. 7 E., Mount Diablo base and meridian.

Plant.—4-horsepower Peerless vertical distillate engine; belt-connected to a 3½-inch Samson horizontal centrifugal pump with 8-inch lagged pulley, catalogue capacity 250–300 gallons per minute. Well, bored, 10 inches by 60 feet, cased for 12 feet; water 14 feet below the surface.

Building cost.—Engine and pump, $325; well, $30; complete plant, $400.

Use in 1910.—Irrigation of 8 acres of vineyard and 2 acres of alfalfa.

Test.—The following results were obtained during a 1¼-hour test of the plant on September 26, 1910:

Consumption of distillate, gallon per hour, 0.75.

Water pumped, gallons per minute, 265.

Speed, revolutions per minute, engine, 310.

Head: 8-foot lift; 19-foot suction. Total static head, 27 feet.

Remarks.—This plant gives results satisfactory in view of its size and irrigation costs that are not unreasonable in consideration of the value of the crops raised. Either plant No. 2 or No. 3, however, if properly located, could do the work of both with much greater economy.

4. A. S. LA SALLE, LODI, CAL. (1906).

Location.—NE. ¼ sec. 25, T. 3 N., R. 6 E., Mount Diablo base and meridian.

Plant.—12-horsepower Hercules distillate engine, 24-inch pulley; belt-connected to a 7-inch Samson horizontal centrifugal pump with 16-inch pulley, catalogue capacity 1,100–1,300 gallons per minute. Wells, three, bored, 8 inches by 90 feet, 10 inches by 90 feet, 17 inches by 90 feet; water 11 feet below the surface.

Building cost.—Engine and pump, $750; complete plant, $1,250.

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Use in 1910.—Irrigation of 20 acres of alfalfa four times at the rate of 2 acres in seven hours.

Test.—The following results were obtained during a 2-hour test of the plant on September 27, 1910:

Consumption of distillate: No satisfactory measurement obtainable. Owner states that 12 gallons are required for a 10-hour run, corresponding to 1.2 gallons per hour.

Water pumped, gallons per minute, 868.

Speed, revolutions per minute: Engine, 300; pump, 410 (catalogue speed, 492).

Head: 8-foot lift; 19-foot suction. Total static head, 27 feet.

Remarks.—This plant apparently operates at high efficiency. Records of water pumped and distillate used are both somewhat doubtful, however, so the apparent efficiency may be too high. The engine has been given excellent care and operates in a very satisfactory manner after eight years' use. A 6-inch pump would be better suited to the plant than the one now in use. The 7-inch pump has to be speeded considerably below its economic capacity in order that the engine may not be too heavily overloaded. The owner of this plant has two other pumping plants on his property. One plant properly located could with much greater economy do the work of all three.

5. J. H. HIGH, LODI, CAL.

Location.—Sec. 18, T. 3 N., R. 7 E., Mount Diablo base and meridian.

Plant.—Byron Jackson pumping unit, consisting of a 5-horsepower electric motor direct-connected to a 3-inch horizontal centrifugal pump; catalogue capacity, 225 gallons per minute. Well, bored, 8 inches by 25 feet; water 8 feet below the surface.

Building cost.—Pumping unit, $513; well, $16; complete plant, $550.

Use in 1910.—Irrigation of small garden and 2 acres of alfalfa; also, for pumping to elevated tank for domestic use.

Test.—The following results were obtained during a 1-hour test on September 28, 1910:

Current used, kilowatt hours per hour, 4.0.

Water pumped, gallons per minute, 300.

Speed of motor and pump, revolutions per minute, 1,150.

Head: 6-foot lift; 14-foot suction. Total static head, 20 feet.

Remarks.—The efficiency of the plant is low, probably on account of the high speed of the pump necessary for pumping to the elevated tank. The result on the lower lift used for irrigation is overspeeding, increased discharge, and low efficiency. The cost per acre of the plant is far too high to be justified by the value of the crops raised. It is essentially a luxury.

6. P. H. TINDELL, LODI, CAL.

Location.—SW. ¼ sec. 18, T. 3 N., R. 7 E., Mount Diablo base and meridian.

Plant.—12-horsepower Fairbanks-Morse distillate engine, 30-inch pulley; belt-connected to a 5-inch Jackson horizontal centrifugal pump with 11½-inch pulley. Catalogue capacity 700 gallons per minute. Well, bored, 8 inches by 150 feet; water 16 feet below the surface; pump installed in 1898, engine in 1906.

Building cost.—Engine, $650; pump, $120; well, $200; complete plant, $1,000.

Use in 1910.—Irrigation of 5 acres of alfalfa six times, 13.5 acres of vineyard once, 28.5 acres of vineyard twice, and 10 acres of vineyard three times. Two to two-and-a-half acres irrigated per day of 12 hours.

Test.—The following results were obtained during a one-hour-test on September 28, 1910:

Consumption of distillate, gallons per hour (from owner's record, no measurement being obtainable), 1.20.

Water pumped, gallons per minute, 605.

Speed, revolutions per minute: Engine, 263; pump, 645.

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Head: 11-foot lift; 20-foot suction. Total static head, 31 feet.

Remarks.—This plant, being operated with fair efficiency to irrigate 52 acres, is subject to the reasonable water cost of $3.60 per acre per year or $2.60 per acre-foot of water pumped. The crops raised can readily stand such a charge. The amount of water used, 1.4 acre-feet per acre per year, is rather low because of the relatively small water requirement of vineyards. The plant is of sufficient capacity to irrigate an area fully twice as great as that now watered from it.

7. GEORGE D. KETTLEMAN, LODI, CAL. (1910).

Location.—SW. ¼ sec. 7, T. 3 N., R. 7 E., Mount Diablo base and meridian.

Plant.—20-horsepower Samson distillate engine, 30-inch pulley; belt-connected to a 6-inch Samson horizontal centrifugal pump with 12-inch pulley, catalogue capacity 800–1,000 gallons per minute. Well, bored, 12 inches by 46 feet, uncased; water 18 feet below the surface. Engine house has substantial cement floor and very heavy concrete engine base.

Building cost.—Engine, $760; pump, $90; well, $30; complete plant, $1,200.

Use in 1910.—Irrigation of 4 acres of alfalfa 10 times at the rate of 0.4 to 0.3 acre per hour. Also as insurance against drought for a large vineyard, though no irrigating water was supplied to the vineyard lands.

Test.—The following results were obtained during a 4-hour test of the plant on September 29, 1910:

Consumption of distillate, gallons per hour, 1.83.

Water pumped, gallons per minute, 914.

Speed, revolutions per minute: Engine, 222; pump, 530 (catalogue speed, 566).

Head: 8-foot lift; 20-foot suction. Total static head, 28 feet.

Remarks.—This plant is remarkable on account of the very high yield of the well, 0.204 second-foot per foot of draw-down. Except for wells in a stream bed, no other well tested in San Joaquin Valley was found to have a capacity 85 per cent as great. A considerable amount of sand has been pumped out and on account of the heavy draft some sand continues in the discharge. The cost of operation in 1910 was $31 per acre irrigated, a very large proportion of the value of the alfalfa raised. The building of such a large plant can not be justified by the use to which it is put. The insurance against drought for the vineyard is perhaps its greatest value. In any case a considerably smaller plant would be fully as useful and much less expensive than the one installed. Only fair efficiency is obtained, the pump being slightly underspeeded and the engine working at small load.

8. CHARLES RASH, LODI, CAL. (1909).

Location.—NW. ¼ sec. 19, T. 3 N., R. 7 E., Mount Diablo base and meridian.

Plant.—10-horsepower Samson distillate engine; 20-inch pulley; belt-connected to a 5-inch Samson horizontal centrifugal pump with 10-inch pulley; catalogue capacity, 600–700 gallons per minute. Well, bored, 12 inches by 48 feet, uncased.

Building cost.—Engine, $350; pump, $75; well, $30; complete plant, $550.

Use in 1910.—Irrigation of 2.5 acres of alfalfa six times. Available for use in vineyard also.

Test.—The following results were obtained during a two-hour test of the plant on September 30, 1910:

Consumption of distillate, gallons per hour, 1.50.

Water pumped, gallons per minute, 406.

Speed, revolutions per minute: Engine, 303; pump, 596 (catalogue speed, 646).

Head: 3-foot lift; 23-foot suction. Total static head, 26 feet.

Remarks.—The plant is well designed in most respects. The pump should be set lower, however, in order to avoid excessive suction lift. The operating efficiency

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was very low during the test. This was due in part to excessive feeding of distillate and in part to the presence of air in the pump. The pump was also somewhat underspeeded. In order to secure reasonable economy, the plant should serve a much greater acreage. As used in 1910, the building cost of the plant is $220 per acre irrigated and the annual cost of irrigation $32 per acre, or $7.80 per acre-foot of water pumped. The crops raised are not of sufficient value to warrant such irrigation costs.

9. JOHN TRETHEWAY, LODI, CAL. (1908).

Location.—NW. ¼ sec. 11, T. 3 N., R. 7 E., Mount Diablo base and meridian.

Plant.—25-horsepower Samson distillate engine; 32-inch pulley; belt-connected to a 7-inch Samson horizontal centrifugal pump with 14-inch pulley (catalogue capacity, 1,100–1,300 gallons per minute). Well, bored, 13 to 8 inches by 137 feet, cased; water 26 feet below the surface.

Building cost.—Engine, $900; pump, $120; well, $100; complete plant, $1,300.

Use in 1910.—Irrigation of garden and of 14 acres of alfalfa, watered twice.

Test.—The following results were obtained during a two-hour test of the plant on October 3, 1910:

Consumption of distillate, gallons per hour, 1.57.

Water pumped, gallons per minute, 425.

Speed, revolutions per minute: Engine, 220; pump, 460 (catalogue speed, 630).

Head: 22-foot lift; 26-foot suction. Total static head, 48 feet.

Remarks.—The operation efficiency of this plant was excellent when all conditions are considered, though the actual results were poor. The engine and pump were underspeeded in order that the capacity of the well might not be exceeded, and the distillate feed choked as far as practicable. A much smaller plant would pump with better efficiency all the water that the well can supply. More extended irrigation from this plant is proposed, but additional water supply from additional wells or from reconstruction of the present well will be necessary to make the plant a success.

10. J. A. HIEB, LODI, CAL. (1907).

Location.—SW. ¼ sec. 15, T. 3 N., R. 7 E., Mount Diablo base and meridian.

Plant.—8-horsepower Fairbanks-Morse distillate engine, 24-inch pulley; belt-connected to a 4-inch Samson horizontal centrifugal pump with 8-inch lagged pulley; catalogue capacity, 400–450 gallons per minute. Well, bored, 8 inches by 46 feet, uncased; water 19 feet below the surface.

Building cost.—Engine, $470; pump, $70; well, $25; complete plant, $650.

Use in 1910.—Irrigation of 4 acres of alfalfa, watered 18 times, at the rate of one-third of an acre per hour.

Test.—The following results were obtained during a one-hour test of the plant on October 4, 1910:

Consumption of distillate, gallons per hour (owner's statement of average requirement, no satisfactory measurement being obtainable), 1.00.

Water pumped, gallons per minute, 444.

Speed, revolutions per minute: Engine, 275 (118 explosions); pump, 750 (catalogue speed, 743).

Head: 7-foot lift; 20-foot suction; total static head, 27 feet.

Remarks.—This plant is well designed, the various parts being well adapted to one another. The efficiency appears to be lower than would be expected, but this is probably due to the rather heavy draft of distillate. The building cost and operation and maintenance costs per acre of land irrigated are unreasonably high in view of the crops raised, for the plant is of sufficient size to irrigate an area twenty times as great as that for which it is actually utilized.

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11. SAM KUMMIS, LODI, CAL.

Location.—SE. ¼ sec. 24, T. 3 N., R. 6 E., Mount Diablo base and meridian.

Plant.—12-horsepower distillate engine (unknown make), 36-inch pulley; belt-connected to a 6-inch Samson horizontal centrifugal pump with 12-inch lagged pulley; catalogue capacity, 800–1,000 gallons per minute. Engine and pump on a portable platform and used to pump from three wells located at convenient points; water about 9 feet below the surface.

Estimated building cost.—Engine, $600; pump, $105; wells, $150; complete plant, $900.

Use in 1910.—Irrigation of 60 acres of almonds and alfalfa, mostly almonds.

Test.—The following results were obtained during a short test on October 4, 1910:

Consumption of distillate, gallons per hour (owner's statement of average use, no measurement being obtainable), 1.20.

Water pumped, gallons per minute, 444.

Speed, revolutions per minute: Engine, 138; pump, 400 (catalogue speed, 566).

Head: 3-foot lift; 24-foot suction; total static head, 27 feet.

Remarks.—The engine is an old one but is still doing good service. The plant operates at low efficiency, chiefly because the speed is very low, this being necessary in order to avoid excessive suction lift. A portable centrifugal pump can be used to advantage only in case the water table is close to the surface of the ground. An 8-horsepower engine and a 4-inch pump would do the work of this plant with greater efficiency and at about two-thirds the building cost.

12. W. G. MICKE, LODI, CAL. (1905).

Location.—NW. ¼ sec. 7, T. 3 N., R. 7 E., Mount Diablo base and meridian.

Plant.—Byron Jackson pumping unit, consisting of a 3-horsepower electric motor direct-connected to a 2-inch horizontal centrifugal pump, catalogue capacity, 100 gallons per minute. Well, bored, 5 inches in diameter, shallow; water 16 feet below the surface.

Building cost.—About $250 for the completed plant.

Use in 1910.—Irrigation of 1.5 acres of alfalfa and garden five times at the rate of 0.06 acre per hour.

Test.—The following results were obtained during a 2-hour test of the plant on October 6, 1910.

Current used, kilowatt-hours per hour, 2.0.

Water pumped, gallons per minute, 108.

Speed of motor and pump, revolutions per minute, 1,700.

Head: 6-foot lift; 19-foot suction. Total static head, 25 feet.

Remarks.—This plant has low efficiency because of its small size. As it lies idle the greater portion of the time, the costs per acre are large even though the current is purchased on the basis of actual use.

13. MRS. WM. P. BEARD, LODI, CAL. (1910).

Location.—NW. ¼ sec. 30, T. 3 N., R. 7 E., Mount Diablo base and meridian.

Plant.—5-horsepower Samson distillate engine, 20-inch pulley; belt-connected to a 3½-inch Samson horizontal centrifugal pump with 7-inch pulley, catalogue capacity, 250–300 gallons per minute. Well, bored, 8 inches by 50 feet, uncased; water 12 feet below the surface.

Building cost.—Engine, $200; pump, $85; well, $4; complete plant, $325.

Use in 1910.—Irrigation of 2 acres of alfalfa and 0.3 acre of garden six times.

Test.—The following results were obtained during an hour-and-a-half test on October 6, 1910.

Consumption of distillate, gallon per hour, 0.80.

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Water pumped, gallons per minute, 249.

Speed, revolutions per minute: Engine, 276; pump, 716 (catalogue speed, 807).

Head: 5-foot lift, 19-foot suction. Total static head, 24 feet.

Remarks.—This plant is operated at low efficiency on account of small size, low speed of pump, and slip of belt. The area irrigated is so small that the building cost per acre and cost per acre of operation and maintenance are excessive.

14. JACOB WAGNER (1904).

Location.—NW. ¼ sec. 19, T. 3 N., R. 7 E., Mount Diablo base and meridian.

Plant.—12-horsepower Fairbanks-Morse distillate engine, 28-inch pulley; belt-connected to a 5-inch Krogh "Pacific" horizontal centrifugal pump with 10-inch pulley, catalogue capacity, 500 to 950 gallons per minute. Well, bored, 12 inches by 115 feet, cased; water 14 feet below the surface.

Building cost.—Complete plant estimated at $1,000.

Use in 1910.—Irrigation of 6 acres of alfalfa watered five times at the rate of 0.07 acre per hour.

Test.—The following results were obtained during a 2-hour test on October 7, 1910.

Consumption of distillate, gallons per hour, 1.25.

Water pumped, gallons per minute, 299.

Speed, revolutions per minute: Engine, 232 (118 explosions); pump, calculated, 650 (catalogue speed, 573).

Head: 11-foot lift; 24-foot suction. Total static head, 35 feet.

Remarks.—As is the case with most plants on which tests were made in this neighborhood, the costs are high by reason of the small area of irrigation. The efficiency of this plant is very low and can not be explained by reasons that were apparent. The discharge is far too small for size and speed of the pump, and there were indications of air leakage in the suction pipe. It may be, however, that poor condition of the pump or clogging of the foot valve is the cause of the low efficiency. The well is deeper than most in the vicinity, and the upper aquifers are cased off. This seems to have been a mistake in construction, as the capacity of the well is relatively small.

15. W. E. BUNKER, GUSTINE, CAL. (1910).

Location.—NW. ¼ sec. 7, T. 9 S., R. 9 E., Mount Diablo base and meridian.

Plant.—100-horsepower Samson four-cylinder vertical distillate engine; direct-connected to a 26-inch Samson horizontal centrifugal pump, catalogue capacity 16,000 gallons per minute.

Building cost.—Engine, $2,850; complete plant, $3,950.

Use.—Pumping for irrigation from a gravity canal through 8-foot suction and 12-foot lift (total static head 20 feet) to high lands. In 1910 156 acres of raw land was watered once at the rate of 0.64 acre per hour using 7.5 gallons of distillate per hour. Plan of irrigation provides for watering 350 acres of alfalfa twice per season.

Remarks.—Though not an underground water development, this plant, which was visited but not tested, is cited as an example of a type of plant being installed at various localities on the west side of San Joaquin Valley in a region highly developed for alfalfa and dairying. The land is reputed to be salable at $30 per acre without and $300 per acre with a water right. Plants of this type extend the use of flood waters to high lands that could not otherwise be watered. Water is supplied by the canals only until sometime in July or August so that the growing season is relatively short. Plants that can quickly irrigate a large area seem to be essential in view of the conditions and the value of the crops seems to warrant rather high costs. From the use of distillate and time for watering it is evident that the plant was not operated at full capacity in 1910.

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16. JOE HOUSE, GUSTINE, CAL. (1909).

Location.—SW. ¼ sec. 6, T. 8 S., R. 9 E., Mount Diablo base and meridian.

Plant.—25-horsepower Samson distillate engine; 14-inch Samson centrifugal pump, catalogue capacity 5,000 to 6,000 gallons per minute.

Building cost.—Engine, $900; complete plant, $1,500.

Use in 1910.—Irrigation of 77 acres of alfalfa twice at the rate of 1.15 acres per hour.

Remarks.—This plant receives its water supply from a gravity canal. The pump operates under water and has a lift of 5.5 feet to 14 acres and 3.5 feet to 63 acres of land. The costs for the season were $19 for distillate at 10 cents a gallon, $1 for lubricating oil, and a merely nominal amount for attendance. The water supply is usually available until some time in July or August. The plant was visited on October 11 but no tests were made. From the foregoing data, supplied by the owner, the efficiency is excellent and the total cost of irrigation about $2.90 per acre. To this should be added $1.50 to $3 per acre charged by the gravity canal company for the water supplied.

17. PATTERSON COLONY, PATTERSON, CAL. (1910).[1]

This plant is located near the new town of Patterson on the west bank of San Joaquin River about 30 miles southwest of Stockton. It is noteworthy as being the largest irrigation pumping plant in San Joaquin Valley. The Rancho del Puerto, or Patterson Ranch, containing about 18,000 acres of land, has been subdivided and is being sold in small holdings with a water right providing for irrigation of the lands with water pumped from San Joaquin River. The irrigable area contains about 14,000 acres and is watered with an assumed duty of water of 1 second-foot to 160 acres from five sections of main canal differing about 13 feet in elevation. The main pumping plant with a capacity of 50,000 gallons per minute (111 second-feet) is located on the river bank and raises the water about 21 feet to the first-lift canal. The first-lift canal supplies water to a large area of land and terminates in a small reservoir supplying a second pumping station that raises water to the second lift canal. The second-lift canal, in turn, supplies water to the land and through a reservoir to a third pumping station. In the same way the fourth and fifth pumping stations and the third, fourth, and fifth lift canals are operated. The canals and reservoirs are lined with concrete and extend about 17,500 feet in a straight line west from the river. The motive power is electricity supplied 19 hours a day (to avoid peak load) at the low rate of three-fourths of a cent per kilowatt-hour actually used. The pumps are of the horizontal centrifugal type, were specially designed for the conditions under which they operate, and gave efficiencies over 75 per cent in tests at the factory. The pump equipment planned for the several stations (about half installed in 1910) is as follows:

TABLE 33.—*Pumping equipment, Patterson colony.*

Station.	Number and size of pumps.	Station capacity in gallons per minute.	Accumulated lift in feet.
1	Four 20-inch	50,000	21
2	Three 20-inch; one 18-inch	46,000	34
3	Two 20-inch; one 15-inch	31,000	47
4	Three 15-inch	18,000	60
5	One 15-inch	6,000	73

[1] The construction of this pumping system has been described in detail by G. C. Stevens (Eng. Record, vol. 62, pp. 284–286, 1910).

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18. P. ALLING, LODI, CAL. (1909).

Location.—NE. ¼ sec. 30, T. 3 N., R. 7 E., Mount Diablo base and meridian.

Plant.—5-horsepower Samson distillate engine, 17-inch pulley; belt-connected to a 4-inch Samson horizontal centrifugal pump with 8-inch lagged pulley, catalogue capacity 400–450 gallons per minute. Well, bored, 6 inches by 46 feet, uncased; water 11 feet beneath the surface.

Building cost.—Engine, $200; pump, $70; well, $25; complete plant, $355.

Use in 1910.—Irrigation of 3.5 acres of alfalfa and a small area of eucalyptus trees and garden eight times at the rate of 0.12 acre per hour.

Test.—The following results were obtained during a 2-hour test on October 13, 1910.

Consumption of distillate, gallons per hour, 0.97.

Water pumped, gallons per minute, 406.

Speed, revolutions per minute: Engine, 328; pump, 642 (catalogue speed, 694).

Head: 7-foot lift; 16-foot suction. Total static head, 23 feet.

Remarks.—The well at this plant has very great capacity for one of so small a diameter. The efficiency of the plant is low and is accounted for by the use of an excess of distillate. The unit costs are high on account of the small area irrigated. The plant is well kept, and with more extensive irrigation operations would give excellent results.

19 AND 20. HOGAN BROS., LODI, CAL. (1904).

Location.—SW. ¼ sec. 19, T. 3 N., R. 7 E., Mount Diablo base and meridian.

Plant.—12-horsepower Fairbanks-Morse distillate engine, 22-inch pulley; belt-connected to a 5-inch Krogh "Pacific" horizontal centrifugal pump with 10-inch pulley, catalogue capacity 500–950 gallons per minute. Well, bored, 12 inches by 46 feet, uncased; water 9 feet below the surface.

Building cost.—Complete plant, $1,000.

Use in 1910.—In conjunction with plant No. 21, for the irrigation of 30 acres of alfalfa, 5 acres of strawberries, and 5 acres of garden truck.

Tests.—The following results were obtained from a 1.5-hour test of the plant on October 5, 1910, and a 2-hour test on October 14, 1910, respectively.

Consumption of distillate, gallons per hour, 1.67–2.12.

Water pumped, gallons per minute, 710–640.

Speed, revolutions per minute: Engine, 267–271 (117–124 explosions); pump, 557–577 (catalogue speed, 524).

Head: 3.5-foot lift; 24.5-foot suction. Total static head, 28 feet.

Remarks.—The engine is an old one. The cylinder has been rebored and at the time of the test needed repacking as it allowed considerable escape of gases. An excess of distillate was being used. The efficiency of the plant was low, but the unit costs are better than for many neighboring plants because a larger relative area is irrigated.

21. HOGAN BROS., LODI, CAL. (1909).

Location.—SW. ¼ sec. 19, T. 3 N., R. 7 E., Mount Diablo base and meridian.

Plant.—12-horsepower Union vertical distillate engine, 18-inch pulley; belt-connected to a 5-inch Globe horizontal centrifugal pump with 14-inch pulley. Well, bored, 12 to 6 inches by 55 feet, cased 25 feet; water 12 feet below the surface.

Building cost.—Complete plant, $1,000.

Use in 1910.—In conjunction with plant No. 20, for the irrigation of 30 acres of alfalfa, 5 acres of strawberries and 5 acres of garden truck.

Test.—The following results were obtained during a 1.5-hour test of the plant on October 14, 1910.

Consumption of distillate, gallons per hour, 1.38.

Water pumped, gallons per minute, 500.

Speed, revolutions per minute: Engine, 343; pump, 427.

Head: 2-foot lift; 25-foot suction. Total static head, 27 feet.

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Remarks.—This plant is operating at low efficiency. This is probably due in part to the great suction lift approaching the limit of practicable operation, and in part to the low speed of the pump. The economic discharge and speed of pump are not known, but it is probably considerably underspeeded and working at low efficiency to develop a relatively small discharge.

22. E. P. TYLER (1910).

Location.—Lot 233, Merced Colony; NE. ¼ sec. 5, T. 8 S., R. 14 E., Mount Diablo base and meridian.

Plant.—35-horsepower General Electric Co. induction motor, 9½-inch pulley; belt-connected to a 10-inch Jackson horizontal centrifugal pump with 21-inch pulley, catalogue capacity, 3,000 gallons per minute. Wells, bored, one 12 to 10 inches by 172 feet, one 12 to 8 inches by 292 feet, one 12 to 8 inches by 220 feet, all cased 40 to 50 feet; water 6 feet below the surface.

Building cost.—Wells, $680; house, $150; installation, $220; pump, motor, and transformers, $1,950; complete plant, $3,000.

Use in 1910.—Irrigation of 4 acres of alfalfa and as demonstration pumping plant for Merced Colony. Will be used to irrigate all crops on a ranch of 174 acres.

Test.—The following results were obtained during a test of the plant on October 18, 1910.

Current used, kilowatt-hours per hour, 28 (owner's record for season).

Water pumped, gallons per minute, 2,160.

Speed, revolutions per minute: Motor, 1,160; pump, 550 (catalogue speed, 550).

Head: 5-foot lift; 23-foot suction. Total static head, 28 feet.

Remarks.—This plant operates with only fair efficiency, and though the pump is apparently speeded properly the discharge is far below the catalogue capacity. There were some indications of air leakage in the suction pipe, but the cause of the poor results was not ascertained with certainty. Electric current was obtained at the rate of 3 cents per kilowatt-hour delivered. The plant costs were high in 1910, but with increase in area irrigated as proposed will be reduced to reasonable amounts.

23. W. R. GIRARD, MERCED, CAL. (1910).

Location.—Lot 185, Merced Colony; SW. ¼ sec. 32, T. 7 S., R. 14 E., Mount Diablo base and meridian.

Plant.—10-horsepower General Electric Co. induction motor, 8½-inch pulley; belt-connected to a 5-inch Samson horizontal centrifugal pump with 14-inch pulley; catalogue capacity 600–700 gallons per minute. Well, bored, 12 inches by 235 feet, cased for about 50 feet; water 6 feet below the surface.

Building cost.—Transformers, $131; motor, $209; pump and accessories, including digging pit and installing pump and motor, $206; building, $50; well and casing, $174; miscellaneous supplies and labor, $38; complete plant, $808.

Use in 1910.—Irrigation of 18 acres of alfalfa.

Test.—The following results were obtained during a 1-hour test of the plant on October 18, 1910.

Current used, kilowatt-hours per hour, 8.6.

Water pumped, gallons per minute, 630.

Speed, revolutions per minute: Motor, 1,160; pump, 700 (catalogue speed, 581).

Head: 3.5-foot lift; 16.5-foot suction. Total static head, 20 feet.

Remarks.—This plant was in good condition when tested. The pump is apparently slightly overspeeded but no reason for appreciable lack of efficiency was apparent. Nevertheless the recorded efficiency was very low. The record of current used, however, was taken from a meter reading without other tests and is probably too high. A meter reading of about 6 kilowatt-hours would have indicated a satisfactory efficiency.

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24. S. M. PATE, MERCED, CAL. (1905).

Location.—NW. ¼ sec. 21, T. 8 S., R. 13 E., Mount Diablo base and meridian.

Plant.—15-horsepower Samson distillate engine, 28-inch pulley; belt-connected to a 6-inch Samson horizontal centrifugal pump with 12-inch pulley, catalogue capacity 800–1,000 gallons per minute. Well, bored, 12 inches in diameter; water 15 feet below the surface.

Building cost.—Complete plant, estimated, $760.

Use in 1910.—Irrigation of several acres of alfalfa.

Test.—The following results were obtained during a test of the plant on October 19, 1910.

Water pumped, gallons per minute, 765.

Speed, revolutions per minute: Engine, 231; pump, 547 (catalogue speed, 592).

Head: 9-foot lift; 21-foot suction. Total static head, 30 feet.

Remarks.—No measurement or owner's record of use of distillate could be obtained. The pump is slightly underspeeded and operates below economical capacity.

25. JESSE RODERIGS, MERCED, CAL. (1907).

Location.—NW. ¼ sec. 10, T. 7 S., R. 13 E., Mount Diablo base and meridian.

Plant.—12-horsepower Samson distillate engine, 24-inch pulley; belt-connected to a 6-inch Samson horizontal centrifugal pump with 12-inch pulley, catalogue capacity 800 to 1,000 gallons per minute. Well, bored, 10 to 7 inches by 84 feet, cased 71 feet; water 9 feet below the surface.

Building cost.—Well and casing, $68; building, $66; complete plant, $700.

Use in 1910.—Irrigation of 9 acres of grapes once, 16 acres of sweet potatoes once a week, and 3 acres of alfalfa five times.

Test.—The following results were obtained during a 1.5-hour test of the plant on October 20, 1910.

Consumption of distillate, gallons per hour, 1.61.

Water pumped, gallons per minute, 400.

Speed, revolutions per minute: Engine, 232; pump, 460 (catalogue speed, 575).

Head: 8-foot lift; 20-foot suction. Total static head, 28 feet.

Remarks.—During the latter part of the test the engine was speeded up to 256 revolutions per minute and the discharge increased to 450 gallons per minute with 4 feet additional draw down. The speed regulator on the engine was worn so that normal speed could not be maintained, the extra speed during the latter part of the test being secured by a temporary makeshift.

Though the pump is underspeeded it is apparently not producing the discharge that it should and probably needs careful overhauling. The engine is using an excess of distillate and leaks badly around the piston. The efficiency is low. The plant is too large for the owner's use as he states that the discharge is as great as he can take care of to advantage. An 8-horsepower engine and a 4-inch pump would be a much more suitable and economical installation for this plant.

26. A. L. SAYRE, MADERA, CAL.

Location.—SE. ¼ sec. 31, T. 11 S., R. 18 E., Mount Diablo base and meridian.

Plant.—50-horsepower electric motor, 16-inch pulley; belt-connected to a 10-inch Jackson horizontal centrifugal pump with 14-inch pulley, catalogue capacity 3,900 gallons per minute. Three wells, bored, 10 to 12 inches by 110 feet, uncased; water 19 feet below the general surface; pump installed in 1903; electric machinery in 1909.

Building cost.—Transformers, $660; motor, $550; wiring, etc., $150; pump, about $550; complete plant, $3,000. A gas producer and gas engine costing $2,800 formerly operated the plant but have been discarded for electric machinery.

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Use in 1910.—Irrigation of 225 acres of vineyard once, and 450 acres of alfalfa five times, and 55 acres of hay and sorghum twice. Operated almost continuously from March or April to October.

Test.—The following results were obtained during a 3.5-hour test of the plant on October 21, supplemented by a brief test on October 23, 1910.

Current used: 36.6 kilowatt-hours per hour by meter measurement, equivalent to 49.0 horsepower.

Water pumped, gallons per minute, 2,300.

Speed, revolutions per minute: Motor, 689; pump, 800 (catalogue speed, 650).

Head: 19.5-foot lift; 21.5-foot suction. Total static head, 41 feet. Suction head by gage, 22.5 inches of mercury or 25.5 feet; hence total head including friction is about 45 feet.

Remarks.—After the test on October 21 the owner protested that the measurement of water must be in error. Accordingly a second measurement was made on October 23 with essentially the same result. Every precaution was taken to insure accurate results, and there can be no serious doubt of the recorded flow. The pump is operated at excessive speed and should under these conditions give a discharge of more than 3,000 gallons per minute, but presumably on account of wear and great suction lift the actual discharge does not exceed 2,300 gallons per minute. As the plant is operated almost continuously throughout the irrigation season to water a large area the unit costs are low. The water-right charge or building cost amount to only $7.50 per acre and the cost of operation and maintenance, including depreciation, renewals, and repairs, amounts to only $3.60 per acre, or $1.50 per acre-foot of water pumped. Irrigation can scarcely fail to be profitable on such terms even with crops of relatively small value.

This plant had a larger discharge than any other tested and was so operated as to give irrigation costs that could be compared favorably with those of any other plant in the valley working under similar conditions as to head and rate charged for power.

27. H. W. PATTERSON, BORDEN, CAL.

Location.—SW. ¼ sec. 8, T. 12 S., R. 18 E., Mount Diablo base and meridian.

Plant.—42-horsepower steam traction engine, 40.5-inch pulley; belt-connected to an 8-inch Jackson horizontal centrifugal pump with 15.5-inch pulley, catalogue capacity, 1,600 gallons per minute. Wells, bored, 10 inches by 96 feet and 10 inches by 134 feet; water 22 feet below the surface. Reservoir with earth embankments and capacity of about 1,000,000 gallons, used to collect water pumped at night; pump installed in 1904; engine purchased in 1909.

Building cost.—Complete plant, $3,500.

Use in 1910.—Irrigation of 30 acres of orchard twice, 50 acres of alfalfa four times, and 40 acres of corn and barley once.

Test.—The following results were obtained during a test of the plant on October 24, 1910.

Consumption of crude oil, gallons per hour, 14.00 (owner's record from test run of 15.5 hours).

Water pumped, gallons per minute, 1,320.

Speed, revolutions per minute: Engine, 229; pump, 588 (catalogue speed, 695).

Head: 19.5-foot lift, 20.5-foot suction (19 inches by gage). Total static head, 41 feet.

Remarks.—This is one of the few steam pumping plants remaining in the valley and the only one tested. The costs are not materially different from those for distillate or electric plants under similar conditions, but the additional attention required in the operation of a steam plant is responsible for its general unpopularity.

The pump is underspeeded and produces a relatively low discharge.

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28. S. W. SKAGGS, BORDEN, CAL. (1907-8).

Location.—SE. ¼ sec. 6, T. 12 S., R. 18 E., Mount Diablo base and meridian.

Plant.—30-horsepower Samson distillate engine, 46-inch pulley; belt-connected to a 6-inch Price horizontal centrifugal pump with 10-inch pulley. Wells, bored, 112 and 186 feet in depth, cased; water 14 to 18 feet below the surface.

Building cost.—Complete plant, $3,200.

Use in 1910.—Irrigation of 60 acres of alfalfa three times. (First two waterings in season given from gravity supply.)

Test.—The following results were obtained during a 2-hour test of the plant on October 24, 1912.

Consumption of distillate, gallons per hour, 3.8.

Water pumped, gallons per minute, 780.

Speed, revolutions per minute: Engine, 204; pump, 905.

Head: 16-foot lift, 25.5-foot suction (by gage). Total static head about 42 feet.

Remarks.—The engine was using an excessive amount of distillate and the efficiency is in consequence low. Great suction lift probably also contributes to the low efficiency. The building and operation and maintenance costs are reasonable.

29. WALTERS BROS., MADERA, CAL. (1908).

Location.—Sec. 32, T. 11 S., R. 18 E., Mount Diablo base and meridian.

Plant.—45-horsepower Hercules distillate engine, 70.5-inch pulley; belt-connected to a 7-inch California (Krogh) horizontal centrifugal pump with 20-inch pulley. Wells, bored, 10 inches by 104 feet, cased, and 10 inches by 174 feet, cased to 134 feet; water 22 feet below the surface.

Building cost.—Complete plant, $3,500, including $500 for pump pit.

Use in 1910.—Irrigation of 50 acres of alfalfa four times; 35 acres of vineyard once, and 15 acres of hay and barley twice, at the rate of 0.35 acre per hour.

Test.—The following results were obtained during a test of the plant on October 25, 1910.

Consumption of distillate, gallons per hour: 4.00 (from owner's statement, no accurate measurement being obtainable).

Water pumped, gallons per minute, 1,900.

Speed, revolution per minute: Engine, 162; pump, 565.

Head: Lift, 21 feet; suction, 25.5 feet (by gage). Total static head about 46 feet.

Remarks.—The efficiency of this plant appears to be very high but both use of distillate and discharge are open to question. The plant is well operated and gives good results as to cost when the head is considered.

30. VALLE-VERDE INVESTMENT CO., FRESNO, CAL. (1909).

Location.—Near Mendota, Cal., in sec. 2, T. 14 S., R. 14 E., Mount Diablo base and meridian.

Plant.—75-horsepower Samson vertical 3-cylinder distillate engine, 40-inch pulley; belt-connected to an 8-inch Jackson double-suction vertical centrifugal pump with 13-inch pulley; catalogue capacity, 1,600 gallons per minute. Wells, bored, 12 inches by 380 feet and 450 feet, cased and 80 feet of casing perforated; 9.6 inches by 414 feet, cased and 80 feet of casing perforated and wrapped spirally with wire of triangular cross section; water 52 feet below the surface.

Building cost.—Complete plant, $6,500, including $1,500 for the two 12-inch wells and $1,800 for the third well.

Use in 1910.—Irrigation of 2 acres of alfalfa eight times, 6 acres of broom corn twice, 40 acres of Egyptian corn twice, 10 acres of Kaffir corn three times, and a half acre of garden twelve times.

Test.—The following results were obtained during a test of the plant on October 27, 1910.

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Consumption of distillate, gallons per hour, 7.27.

Water pumped, gallons per minute, 1,080.

Head: 51-foot lift; 31-foot suction (by gage). Total static head about 82 feet.

Remarks.—This plant is the only one on the "west side" that was tested. The depth to water is over 50 feet and the flow of water, occurring in fine sand, is not free. The two wells without special casing give a comparatively small flow because of clogging with sand. The third well gives much better results, being fitted with a special screen such as is described by Bowman.[1] After all, however, the suction head is excessive and accounts for the fairly low efficiency of the plant and the small discharge of the pump.

The building cost of the plant is about $34 per acre of land that it will irrigate, though with the small area now watered the cost is over $100 per acre. The cost of operation and maintenance is now about $8.40 per acre-foot of water pumped but could be reduced to $4.10 per acre-foot if operated for the irrigation of a larger area. The costs, even under the best conditions, must be a relatively high proportion of the value of ordinary crops raised and every care should be taken to secure economy in the operation of such a plant if it is to be used successfully.

21. ROSEDALE WATER CO., PORTERSVILLE, CAL. (1907).

Location.—Sec. 3, T. 22 S., R. 28 E., Mount Diablo base and meridian.

Plant.—20-horsepower Westinghouse induction motor; direct-connected to a 4-inch California (Krogh) horizontal centrifugal pump. Wells located adjacent to and on both sides of Tule River as follows: Dug well 28 feet deep; bored well 12 inches by 35 feet; shaft or dug well 18 feet deep. Wells connected by tunnel or piping.

Building cost.—Complete plant estimated, $1,300, not including extensive system for water delivery.

Use in 1910.—Operated continuously from April to October 15 for four and five waterings of 22 citrus orchards aggregating 177 acres in area.

Test.—The following results were obtained during a test of the plant on November 3, 1910.

Current used, horsepower, 23.00 (from power company's bill), equivalent to 17.15 kilowatt-hours per hour.

Water pumped, gallons per minute, 565.

Speed, of motor and pump, revolutions per minute, 1,125.

Head: 74-foot lift; 5-foot suction. Total static head, 79 feet.

Remarks.—This plant is owned and operated in cooperation by 22 orchardists. Each pays to the cooperative organization 50 cents per hour for the time that water is supplied by the plant to his lands. In this manner all receive irrigation water much more economically than if each owned a plant for his own exclusive use. Being operated continuously throughout the irrigation season the cost of pumping water amounts to less than $2.50 per acre-foot even though the head is 79 feet. The wells are located on the edge of Tule River and generally give a full supply of water with little drawdown. The water level fluctuates considerably during the season, however, and the plant can not be run at full capacity at all times. The water is pumped through 900 feet of 12-inch pipe to the highest land to be irrigated and then flows in open cement flumes to the various orchards.

22. D. C. SETTLEMIRE, PORTERSVILLE, CAL. (1910

Location.—SW. ¼ sec. 12, T. 22 S., R. 27 E., Mount Diablo base and meridian.

Plant.—12-horsepower Fairbanks-Morse distillate engine; belt-connected to a Downie geared double pump head. Well, bored, 12 inches by 180 feet; water 33 feet below the surface.

[1] Bowman, Isaiah, Well-drilling methods: U. S. Geol. Survey Water-Supply Paper 257, p. 98, 1911.

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Building cost.—Complete plant, $2,500.

Use in 1910.—Irrigation of 9 acres of young orange trees and small garden five times. Will be utilized for irrigation of about 40 acres.

Test.—The following results were obtained during a test of the plant on November 3, 1910:

Consumption of distillate, gallons per hour, 1.00 (owner's record, no satisfactory measurement being obtainable).

Water pumped, gallons per minute, 165.

Speed: Engine, 264 revolutions per minute (66 explosions); pump, strokes per minute, 32.

Head: Cylinder, 100 feet below pump head. Total static head, about 50 feet.

Remarks.—The test of this plant was not wholly satisfactory. The pump was evidently discharging far below its rated capacity and the engine working on a very light load. The efficiency was consequently low. The small discharge could be explained satisfactorily by a worn-out or clogged valve or other similar condition at the cylinder.

Under the conditions of operation in 1910 the costs of irrigation were excessive. With the pump in good condition and the entire 40-acre tract irrigated, however, the costs would be reasonable.

33. G. A. MARTIN, PORTERSVILLE, CAL. (1909).

Location.—SE. ¼ sec. 12, T. 22 S., R. 27 E., Mount Diablo base and meridian.

Plant.—3-horsepower Fairbanks-Morse induction motor; belt-connected to a single-action Krogh pump head with 19-inch stroke. Well, bored, 10 inches by 100 feet; water 60 feet below the surface.

Building cost.—Complete plant, $900.

Use in 1910.—Irrigation of 7 acres of oranges and 3 acres of garden truck five times at the rate of 0.042 to 0.037 acre per hour.

Test.—The following results were obtained during a test of the plant on November 4, 1910:

Current used, 3.3-horsepower (from power company's bill), equivalent to 2.46 kilowatt-hours per hour.

Water pumped, gallons per minute, 38.3.

Speed: Motor, revolutions per minute, 1,800; pump, strokes per minute, 21.

Head: Cylinder, 94 feet below the pump. Total static head, about 70 feet.

Remarks.—The efficiency of this plant is very low, but, aside from the small size of the machinery, no poor working conditions were apparent. The costs, though high, are no doubt warranted by the relatively high returns from citrus culture.

34. R. W. JOB, PORTERSVILLE, CAL. (1910).

Location.—NE. ¼ sec. 13, T. 22 S., R. 27 E., Mount Diablo base and meridian.

Plant.—15-horsepower General Electric induction motor; belt-connected to a No. 3 double-action straight-line deep-well pump with 30-inch stroke. Well, bored, 12 inches by 285 feet; water 80 feet below the surface.

Building cost.—Pump and motor, $2,400; well, $900; complete plant, $3,500.

Use in 1910.—Irrigation of 80 acres of young orange trees five to six times.

Test.—The following results were obtained during a test of the plant on November 4, 1910:

Current used, 15.32-horsepower (from power company's bill), equivalent to 11.43 kilowatt-hours per hour.

Water pumped, gallons per minute, 210.

Speed: Motor, 1,185 revolutions per minute; pump, 16.5 strokes per minute.

Head: Cylinder, 120 feet below the pump. Total static head, about 140 feet.

Remarks.—This plant operates with satisfactory efficiency, and the costs of irrigation are reasonable for citrus culture.

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35. BLACHERNE WATER CO., PORTERSVILLE, CAL. (1907).

Location.—SE. ¼ sec. 23, T. 21 S., R. 27 E., Mount Diablo base and meridian.

Plant.—15-horsepower Westinghouse induction motor; belt-connected to a No. 30 power head Ames deep-well pump with 24-inch stroke. Well, bored, 10 inches by 112 feet; water about 60 feet below the surface.

Building cost.—Pump, motor, etc., $2,325; well and 12 acres of land, $1,200; complete pumping plant, about $3,500; complete system, including pumping plant, 1,200 feet of 8-inch wood-stave pipe, about 6,600 feet of cement flume, and 12 acres of land, $4,800.

Use in 1910.—Operated practically continuously from April to October, inclusive, for the irrigation of 45 acres of oranges.

Test.—The following results were obtained during a test of the plant on November 5, 1910:

Current used, 16.00 horsepower (from power company's bills), equivalent to 11.9 kilowatt-hours per hour.

Water pumped, gallons per minute, 172.

Speed: Motor, 1,133 revolutions per minute; pump, 22 strokes per minute.

Head: 80 feet below and 125 feet above the power head. Total static head about 205 feet.

Remarks.—This plant pumps water through 1,200 feet of 8-inch wood-stave pipe to a hill crest from which it flows through about 6,600 feet of cement flume to five citrus orchards aggregating 45 acres. The plant is owned and operated by a cooperative stock company, the stockholders being owners of the lands irrigated. Each irrigator is assessed $2 per acre per month for water service. The stave pipe leaks appreciably, but the plant, nevertheless, shows high efficiency. The costs of operation, though high per acre of land irrigated on account of the great lift, are warranted by the value of the citrus-fruit production.

36. HILO PUMP, PORTERSVILLE, CAL. (1904).

Location.—NW. ¼ sec. 23, T. 21 S., R. 27 E., Mount Diablo base and meridian.

Plant.—30-horsepower Westinghouse induction motor; direct-connected to a 4-inch Price horizontal centrifugal pump. Well, bored, 12 inches by 165 feet, water 30 feet below the surface.

Building costs.—Complete plant, $3,500.

Use in 1910.—Irrigation of 100 acres of citrus orchards.

Tests.—The following results were obtained during tests on the high and low lifts on November 5, 1910:

Current used, 30.10 horsepower (from power company's bills), equivalent to 22.5 kilowatt-hours per hour.

Water pumped, gallons per minute: High lift, 410; low lift, 383.

Speed: Motor and pump, 868 revolutions per minute.

Head: 92-foot (high) lift; 25.5-foot (low) lift; 25-foot suction. Total static head, 117 feet (high) and 50 feet (low).

Remarks.—This plant pumps water for a small area under the low lift at the pumping plant and for 90 or more acres under the high lift through 700 feet of 12-inch wood-stave pipe to a cement ditch from which distribution is made to the several orchards. An assessment of $1.75 per acre per month is made for water service. Among the expenses of operation are the wages at $22.50 per month of a superintendent, who operates the plant and distributes the water. The efficiency of the plant is good and the costs are reasonable for the lift.

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27. COPO DE ORO WATER CO., PORTERSVILLE, CAL.

Location.—SW. ¼ sec. 14, T. 21 S., R. 27 E., Mount Diablo base and meridian.

Plant.—30-horsepower Westinghouse motor; belt-connected to a double plunger Ames pump head, 11-inch cylinder, 28-inch stroke. Well, dug 60 feet, then tunneled and drilled in rock to about 150 feet; water enters about 50 and 150 feet and stands 20 to 30 feet below surface.

Building cost.—Complete plant, $6,000.

Use in 1910.—Irrigation of citrus orchards. Water users charged $1 per hour for use of plant.

Test.—The following results were obtained during a test of the plant on November 5, 1910:

Current used: 23.00 horsepower (from power company's bill), equivalent to 17.15 kilowatt-hours per hour.

Water pumped, gallons per minute, 237.

Speed: Motor, revolutions per minute, 893; pump, 25 strokes per minute.

Head: Cylinder 60 feet below the pump. Total static head about 147 feet.

Remarks.—This plant is located in the center of an area of citrus orchards in a narrow depression between two hills. The location is not favorable for an abundant water supply. Water is pumped through about 1,000 feet of pressure pipe to a concrete flume on the hillside at the upper edge of the citrus orchards. The flume is well constructed and carries the water perhaps a mile to the most distant orchard irrigated. A new plant more favorably located for water supply has been built by the company but was not in operation when visited. Detailed operation statistics were not available.

28. SUNNYSIDE WATER CO., PORTERSVILLE, CAL.

Location.—SW. ¼ sec. 14, T. 21 S., R. 27 E., Mount Diablo base and meridian.

Plant.—50-horsepower Westinghouse motor; belt-connected to two No. 30 power-head Ames double plunger pumps with 24-inch stroke. Three wells, bored, 12 inches by 100 to 150 feet; water 30 to 50 feet below the surface.

Building cost.—Complete plant, $6,000 (?).

Use in 1910.—Irrigation of orange orchard five times.

Test.—The following results were obtained during a test of the plant on November 5, 1910.

Water pumped, gallons per minute, 547.

Speed: Motor, revolutions per minute, 898; pump, 22 strokes per minute.

Head: Cylinder 100 feet below the pump. Total static head, about 180 feet.

Remarks.—Only meager information as to this plant could be secured at the time the brief test was made.

29. J. H. LEACH, PORTERSVILLE, CAL.

Location.—SW. ¼ sec. 23, T. 21 S., R. 27 E., Mount Diablo base and meridian.

Plant.—2-horsepower vertical Fairbanks-Morse distillate engine; belt-connected to a 2-inch Price horizontal centrifugal pump. Well, bored, 6 inches by 80 feet; water 10 feet below surface.

Building cost.—Engine, $120; pump, $35; well, $75; complete plant, $250.

Use in 1910.—As auxiliary to gravity supply for 3 acres of garden, about 300 hours aggregate run.

Test.—The following results were obtained during a test of the plant November 7, 1910:

Consumption of distillate, gallons per hour, 0.15.

Water pumped, gallons per minute, 23.

Speed, revolutions per minute: Engine, 400 (87 explosions); pump, 1,060.

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Head: 4-foot lift; 19-foot suction. Total static head, 23 feet.

Remarks.—This is a fair type of the small plant suitable for use in truck gardens. The suction pipe was evidently leaking air somewhat and the efficiency was low. Nevertheless the plant was doing good service as an auxiliary to a gravity water supply. A renewal of the suction pipe would probably be required to place it on an efficient working basis.

40. J. J. ANDERSON, PORTERSVILLE, CAL. (1910).

Location.—Sec. 23, T. 21 S., R. 27 E., Mount Diablo base and meridian.

Plant.—6-horsepower Victor vertical distillate engine; belt-connected to a 6-inch Jackson horizontal centrifugal pump, catalogue capacity 400 gallons per minute. Well bored to 90 feet but filled to 43 feet depth.

Building cost.—Engine and pump, $400; complete plant, $500.

Use in 1910.—Supplement to gravity supply on 17.5 acres of orchard and garden.

Test.—The following results were obtained during a test of the plant on November 7, 1910:

Consumption of distillate, gallons per hour, 0.92 (owner's record).

Water pumped, gallons per minute, 406.

Speed, revolutions per minute: Engine, 370.

Head: 9-foot lift; 22-foot suction. Total static head, 31.

Remarks.—This plant was installed in July, 1910, and used successfully during the season as a supplement to a gravity supply. The plant was unhoused and not in the best of condition. A loose belt caused excess of slip and consequent loss of efficiency. Pump speed could not be measured. The cost per acre, though high, is not unreasonable.

41. BADGER IRRIGATION CO., NEAR EXETER, CAL.

This plant is especially noteworthy for the high lifts. Three primary pumping plants lift the water from wells for the irrigation of low lands and to a reservoir from which a fourth plant lifts it to supply laterals at elevations of 66, 200, 247, 300, and 412 feet above the pumps. The maximum irrigation lift is about 490 feet. As originally planned there were laterals at elevations of 530 and 586 feet above the level of the pumps, but these were abandoned. An orange orchard of 190 acres is irrigated by the system, which is reported by the company to have cost $18,000. The irrigation season is about five and a half months, including parts of April and October.

The following data as to the primary plants were furnished by the company:

1. 7.5-horsepower, type C, Westinghouse induction motor, operating at 110 volts; 6-inch Jackson horizontal centrifugal pump (catalogue capacity 400 gallons per minute).

2. 15-horsepower, type C, Westinghouse induction motor, operating at 110 volts; Hooker double-acting deep-well pump.

3. 7.5-horsepower, type C, Westinghouse induction motor, operating at 110 volts; W. T. Garrett single-acting deep-well pump.

The three plants use about 28.4 horsepower and supply about 2 second-feet of water.

The fourth or high-lift plant is equipped with a 75-horsepower, type C, Westinghouse induction motor operating at 2,000 volts and two W. T. Garrett double-acting triplex pumps. These pumps are reported to give a discharge of 1.5 second-feet at all lifts up to the 300-foot level and 1 second-foot at the 412-foot level. The pulley arrangement is such that speeds suitable to the various lifts may be given to the pumps.

The cost of irrigation is necessarily very high with a plant operating under such an unusual head, but it appears to be warranted by the returns from the citrus crops grown. The company officials state that they are satisfied with the results obtained.

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42. TOM POGUE, EXETER, CAL. (1909).

Location.—SE. ¼ sec. 2, T. 19 S., R. 26 E., Mount Diablo base and meridian.

Plant.—5-horsepower General Electric induction motor, operating at 220 volts; belt-connected to a Garrett single-acting deep well pump, 8-inch cylinder. Well bored 12 inches by 112 feet, water 36 feet below the surface.

Building cost.—Pump, $540; well, $100; complete plant, $1,400.

Use in 1910.—Irrigation of garden, orchard, and alfalfa.

Test.—The following results were obtained during a test of the plant on November 9, 1910:

Current used: 5.05 horsepower (from power company's bill), equivalent to 3.8 kilowatt-hours per hour.

Water pumped, gallons per minute, 179.

Speed: Motor, revolutions per minute, 1,167; pump strokes per minute, 29.

Head: Cylinder 60 feet below the pump; lift 13 feet. Total static head, about 60 feet.

Remarks.—This plant was giving satisfactory results.

43. P. W. PRESTON, EXETER, CAL. (1907).

Location.—E. ½ NW. ¼ sec. 2, T. 19 S., R. 26 E., Mount Diablo base and meridian.

Plant.—10-horsepower Fairbanks-Morse distillate engine, 39-inch pulley; belt-connected to a 4-inch Price horizontal centrifugal pump with 8-inch pulley. Well, bored, 8 inches by 90 feet in pit 35 feet deep; water 36 feet below the surface.

Building cost.—Engine, $550; pump and pipe, $151; well and pit, $200; complete plant, $1,000.

Use in 1910.—Irrigation of 26 acres of citrus fruits.

Test.—The following results were obtained during a 2-hour test of the plant on November 9, 1910:

Consumption of distillate, gallons per hour, 1.00 (approximate).

Water pumped, gallons per minute, 320.

Speed, revolutions per minute: Engine, 274 (105 explosions); pump, 1,320.

Head: 37-foot lift; 14-foot suction. Total static head, 51 feet.

Remarks.—This plant was giving good service. It is of sufficient capacity to irrigate a considerably larger area than it serves, but the cost per acre is warranted for citrus culture.

44. L. W. SHAW, EXETER, CAL. (1910).

Location.—W. ½ SW. ¼ SE. ¼ sec. 35, T. 18 S., R. 26 E., Mount Diablo base and meridian.

Plant.—8-horsepower Samson distillate engine, 28-inch pulley; belt-connected to a 3½-inch Samson horizontal centrifugal pump with 7-inch pulley, catalogue capacity of 250–300 gallons per minute. Well, bored, 10 inches by 90 feet; water 36 feet below the surface.

Building cost.—Well, $300; complete plant, $1,000.

Use in 1910.—Irrigation of 15 acres of oranges and about 4 acres of alfalfa. About 800 gallons of distillate used.

Test.—The following results were obtained during a test of the plant on November 9, 1910:

Consumption of distillate, gallons per hour, 0.875.

Water pumped, gallons per minute, 220.

Speed, revolutions per minute: Engine, 263; pump, 1,004.

Head: 31-foot lift; 24-foot suction. Total static head, 55 feet.

Remarks.—The efficiency of this plant was only fair. The pump was underspeeded, but even under this condition the water was drawn down so far as to create a rather

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large suction head. The machinery was apparently in good condition, the faults of the plant being in design. The pump is too high above the water level and the pulley size not in proper ratio.

45. MR. BRISCOE, LINDSAY, CAL. (1910).

Location.—NE. ¼ sec. 30, T. 19 S., R. 27 E., Mount Diablo base and meridian.

Plant.—3-horsepower General Electric induction motor direct-connected to a 2-inch type B Krogh horizontal centrifugal pump, catalogue capacity of 100 gallons per minute. Well, bored, 10 inches by 80 feet, filled up to 54-foot depth.

Building cost.—Pump and motor, $425; well, $300; complete plant, $900.

Test.—The following results were obtained during a test of the plant on November 10, 1910:

Current used: 3.59 horsepower (from power company's bill), equivalent to 2.68 kilowatt hours per hour.

Water pumped, gallons per minute, 116.

Speed, revolutions per minute, 1,800.

Head: 28-foot lift; 18-foot suction. Total static head, 46 feet.

Remarks.—The power consumption at this plant is unreasonably high, with consequent low efficiency. The cause of excessive power use was not apparent.

46. O. S. GARD, LINDSAY, CAL.

Location.—NW. ¼ sec. 31, T. 19 S., R. 27 E., Mount Diablo base and meridian.

Plant.—3-horsepower Bullock motor direct-connected to a 2-inch Eclipse horizontal centrifugal pump. Well, bored, 10 inches by 77 feet; pit 32 feet deep.

Building cost.—Complete plant, $350.

Use in 1910.—Irrigation of 20 acres of oranges with four months' steady operation.

Test.—The following results were obtained during a test of the plant on November 10, 1910:

Current used: 3.47 horsepower (from power company's bill), equivalent to 2.59 kilowatt hours per hour.

Water pumped, gallons per minute, 72.

Speed, revolutions per minute, 1,700.

Head: 10-foot lift; 30-foot suction. Total static head, 40 feet.

Remarks.—The pump and motor were installed so that they could be raised or lowered by sliding in a frame. When tested the pump and motor had been raised nearly to the surface for the winter and was practically out of commission. The suction head was therefore very great and the indicated efficiency of the plant low. The test does not show what the plant could do under normal conditions.

47. HILL PLANT OF DR. C. B. ROOT, LINDSAY, CAL.

Locations.—NE. ¼ sec. 6, T. 20 S., R. 27 E., Mount Diablo base and meridian.

Plant.—7½-horsepower Westinghouse type C induction motor; belt-connected to a double-acting Whitmer deep-well pump. Well, bored, 203 feet deep; water, 60 feet below the surface. Discharge through 750 feet of 4-inch pipe.

Building cost.—Well, $200; complete plant, $1,500.

Use in 1910.—In conjunction with plant No. 48, used for the irrigation of 70 acres of oranges.

Test.—The following results were obtained during a test of the plant on November 10, 1910:

Current used: 7.44 horsepower (from power company's bill), equivalent to 5.55 kilowatt-hours per hour.

Water pumped, gallons per minute, 96.

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Speed: Motor, revolutions per minute, 1,143; pump, strokes per minute, 32.

Head: 75 feet above and about 75 feet below the power head. Total static head 150 feet.

Remarks.—This plant has been in use several years and has given reasonably satisfactory service throughout.

48. LOW-LEVEL PLANT OF DR. C. B. ROOT, LINDSAY, CAL.

Location.—NE. ¼ sec. 6, T. 20 S., R. 27 E., Mount Diablo base and meridian.

Plant.—7½-horsepower Westinghouse type C induction motor; belt-connected to a double-cylinder, single-plunger Garrett deep-well pump. Well, bored, 201 feet deep.

Building cost.—Well, $500; complete plant, $1,500.

Use in 1910.—In conjunction with plant No. 47, used for the irrigation of 70 acres of oranges.

Test.—The following results were obtained during a test of the plant on November 10, 1910:

Current used: 7.92 horsepower (from power company's bill), equivalent to 5.91 kilowatt-hours per hour.

Water pumped, gallons per minute, 161.

Speed: Motor, revolutions per minute: 1,165; pump strokes per minute, 28.

Head: 25 feet above and about 75 feet below the power head. Total static head 100 feet.

Remarks.—This is a well-kept plant that gives satisfactory results. The pumped water is distributed through cement pipe.

49. ROEDING & WOOD NURSERY CO., EXETER, CAL. (1909).

Location.—NE. ¼ sec. 14, T. 19 S., R. 26 E., Mount Diablo base and meridian.

Plant.—40-horsepower Western distillate engine; belt-connected to a No. 28 power head, single-acting Pomona deep-well pump. Well, bored, 15 inches by 100 feet; cylinder 68 feet down; 86 feet to main aquifer.

Building cost.—Engine and pump, $3,370; building, $250; well, $500. Complete plant about $4,120, exclusive of iron-pipe line nearly a mile long.

Use in 1910.—For irrigation of 13 acres of alfalfa and 5 acres of citrus nursery at plant and about 160 acres of olives and nursery at high levels; being used as supplement to gravity supply on 100 acres of this area.

Test.—The following results were obtained during a test of the plant on November 11, 1910.

Consumption of distillate, gallons per hour, 1.50.

Water pumped, gallons per minute, 393.

Speed: Engine, revolutions per minute, 224 (28 explosions); pump, strokes per minute, 18.

Head: 5 feet above and 38 feet below the pump head. Total static head, 43 feet.

Remarks.—The plant is designed for operation under widely differing conditions. At the plant about 25 acres, chiefly in alfalfa and nursery trees, is to be irrigated. The greater part of the irrigable area, however, is located at the edge of the foothills, nearly a mile distant. The owners report that at the end of 3,760 feet of 7½-inch pipe the total head, including friction, is 173.5 feet, and the pump delivers 1.03 second-feet against this head when the engine uses 2.75 gallons per hour of distillate. An additional 1,000 feet of pipe carries the water to a level 150 feet higher, where about 0.5 second-foot can be delivered. The test made was on the lowest lift, where the operation would be least economical.

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50. LAUREL COLONY, TULARE, CAL. (1908).

Location.—Sec. 36, T. 19 S., R. 23 E., Mount Diablo base and meridian.

Plant.—10-horsepower Westinghouse type C induction motor, direct-connected to a 6-inch Krogh California centrifugal pump. Well, bored, 10 inches by 465 feet.

Building cost.—Well, $1,800; machinery, $1,000; complete plant, $3,000.

Use in 1910.—Irrigation of 320 acres, chiefly alfalfa land.

Test.—The following results were obtained during a test of the plant on November 14, 1910:

Current used: 14.00 horsepower, equivalent to 10.4 kilowatt-hours per hour.

Water pumped, gallons per minute, 910.

Speed, revolutions per minute, 1,100.

Head: Lift, 10 feet; suction, 20 feet. Total static head 30 feet.

Remarks.—This plant is noteworthy for the relatively high cost of the well. It is located in an artesian belt and the water rises within 1.5 feet of the surface. Flowing wells are not unusual in the locality. The plant is operated for the benefit of several settlers. The costs per acre are low, the capacity duty being about 1 second-foot to 160 acres. The motor is run at considerable overload. A second plant of about the same size would be required to produce maximum yields from the entire area covered.

51. DR. M. S. CHARLES, TULARE, CAL. (1910).

Location.—Sec. 4, T. 20 S., R. 24 E., Mount Diablo base and meridian.

Plant.—3-horsepower Westinghouse type CCL induction motor; belt-connected to a 2-inch Golden West horizontal centrifugal pump. Well, bored, 5 inches by 70 feet.

Building cost.—Motor and transformer $210; complete plant, including 460 feet of 4-inch pipe, $518.

Use in 1910.—Irrigation of 32 acres of garden and alfalfa land.

Test.—The following results were obtained during a test of the plant on November 15, 1910:

Current used: 4.5 horsepower (from company's test) equivalent to 3.36 kilowatt-hours per hour.

Water pumped, gallons per minute, 135.

Speed, revolutions per minute: Motor, 1,702; pump, about 1,490.

Head: 9-foot lift; 16-foot suction. Total static head, 25 feet.

Remarks.—The apparent efficiency of this plant is very low. The machinery was new and the installation seemed to be first class. The consumption of power had been tested by the company shortly before test on November 15. A ground on the electric circuit or an obstruction in the discharge pipe would seem to be the most likely difficulties.

52. G. H. HAUSCHILDT, TULARE, CAL.

Location.—Sec. 5, T. 20 S., R. 24 E., Mount Diablo base and meridian.

Plant.—3-horsepower Westinghouse type CCL induction motor, direct-connected to a 3-inch Krogh California horizontal centrifugal pump. Well, bored, 10 inches by 850 feet.

Building cost.—Well, $1,480; complete plant, $2,020.

Use in 1910.—Irrigated 40 acres of alfalfa four times with about 6 inches of water.

Test.—The following results were obtained during a test of the plant on November 16, 1910:

Current-used: 3.42 horsepower (from power company's bill), equivalent to 2.55 kilowatt-hours per hour.

Water pumped, gallons per minute, 180.

Speed, revolutions per minute, 1,700.

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Head: 10-foot lift; 19-foot suction. Total static head, 29 feet.

Remarks.—Discharge is through 150 feet of 6-inch wood-stave pipe to a 0.5-acre reservoir, which is used to store water at night and afford a larger irrigation head.

53. F. S. McADAMS, TULARE, CAL. (1910).

Location.—SW. ¼ sec. 13, T. 20 S., R. 23 E., Mount Diablo base and meridian.

Plant.—10-horsepower General Electric induction motor; direct-connected to a 5-inch Price horizontal centrifugal pump. Well, bored, 12 inches by 163 feet; cased.

Building cost.—Well, $325; complete plant, $845.

Use in 1910.—Irrigation of 90 acres of alfalfa. Planned to irrigate 120 acres. Operated continuously from April to August 1.

Test.—The following results were obtained during a test of the plant on November 18, 1910:

Current used: 9.7 horsepower (10.25 horsepower from power company's bill).

Water pumped, gallons per minute, 720.

Speed, revolutions per minute, 1,172.

Head: 6-foot lift; 22-foot suction. Total static head 28 feet.

Remarks.—This is one of the better class plants and is operated so as to give relatively low costs per acre irrigated.

54. W. J. McADAMS, TULARE, CAL. (1909).

Location.—SW. ¼ sec. 18, T. 20 S., R. 24 E., Mount Diablo base and meridian.

Plant.—15-horsepower Westinghouse type CCL induction motor, direct-connected to a 7-inch Price horizontal centrifugal pump. Wells, bored, 12 inches in diameter, one 90 feet and the other 127 feet in depth.

Building cost.—Pump and motor, $750; complete plant, $1,400.

Use in 1910.—Irrigation of 200 acres of alfalfa. Operated continuously for 6 months. Additional area of 40 acres being prepared for irrigation.

Test.—The following results were obtained during a test of the plant on November 18, 1910:

Current used: 19.21 horsepower (from power company's bill), equivalent to 14.34 kilowatt-hours per hour.

Water pumped, gallons per minute, 1,450 (approximately).

Speed, revolutions per minute, 846.

Head: 10-foot lift; 19-foot suction. Total static head, 29 feet.

Remarks.—This plant is typical of the best practice for irrigation of alfalfa.

55. L. G. MARTIN, TULARE, CAL. (1910).

Location.—NW. ¼ sec. 18, T. 20 S., R. 24 E., Mount Diablo base and meridian.

Plant.—10-horsepower Alamo distillate engine, 24-inch pulley, belt-connected to a 5-inch Price horizontal centrifugal pump, 8.5-inch pulley. Well, bored, 12 inches by 110 feet.

Building cost.—Well, $220; engine and pump, $650; complete plant, $900.

Use in 1910.—Installed in late summer and used for watering stock and irrigating 40 acres of alfalfa. Will be used for irrigation of 80 acres of alfalfa.

Test.—The following results were obtained during a test of the plant on November 18, 1910:

Consumption of distillate, gallons per hour, 1.45.

Water pumped, gallons per minute, 695.

Speed, revolutions per minute: Engine, 264; pump, 695.

Head: 9-foot lift; 17-foot suction. Total static head, 26 feet.

Remarks.—This is a new plant and the operation shows rather low efficiency. The vacuum gage showed loss of head in the suction pipe, probably due to some obstruction.

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TABULATED RESULTS OF PUMPING TESTS.

In Table 34 the data derived from the preceding pumping plant tests and information collected at the time the tests were made are assembled so as to present in concise form the chief factors of engineering interest in each case.

The number in the first column corresponds to the number used in the description of each plant and its test.

The second and third columns give the discharge in gallons per minute and in second-feet, generally as determined by test, though in a few specified cases as reported by the owner or operator of the plant.

The fourth column, of drawdown, shows the extent to which the water level in the wells was lowered during the tests. Generally about 20 minutes was required to reduce the water level to an elevation that remained constant thereafter with uniform discharge from the plant.

The capacity of the well (column 5) is derived from the third and fourth columns, being the discharge in second-feet divided by the drawdown in feet. This capacity is only an average figure, however, as each succeeding foot of drawdown probably causes an increasingly greater yield of the well.

The total static head represents the difference in elevation between the water level in the well during operation and the level at which the water is discharged from the pumping plant.

The useful water horsepower is derived from the discharge and the total static head, being the discharge in pounds per second (the discharge in second-feet $\times$ 62.3) multiplied by the total static head in feet, divided by 550 (the number of foot-pounds per second in one horsepower).

The column giving the length of irrigation season in days is based on what information could be secured as to the customary period during which crops were irrigated in the several localities examined.

In the ninth column is shown in terms of days of continuous operation the length of time the plants were operated in 1910. Comparison of this column with that preceding indicates that in general the plants were operated for only a small part of the irrigating season. This shows one of the principal sources of the high cost of irrigation by pumping, for the fixed costs on a pumping plant that is lying idle mount up rapidly and result in a high cost per acre actually irrigated.

The columns giving capacity of plant show respectively the amounts of water that could be delivered if the plants were operated 80 per cent of the irrigation season, and the amounts that were actually delivered in 1910. These columns show, like columns 8 and 9, that the large proportion of the time that the plants are idle is a principal factor in making the cost of pumping higher than is necessary.

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The figures of column 12, giving the acreage irrigable with maximum draft of 1 second-foot to 80 acres, is obtained from the figures in column 3, the actual discharge in second-feet. The acreages actually irrigated in 1910 are given in column 13.

Column 14, giving the duty of water in 1910 (obtained from the figures of columns 11 and 13), is of principal interest in showing the variation in irrigation practice among individual ranchers. The figures also indicate roughly the amount of water actually delivered to the land for irrigation.

The item of fuel oil has been expressed in three ways—the amount of fuel oil (distillate) used per hour by the engines tested and the corresponding costs per day and per useful water horsepower per day. The cost of fuel oil was taken as the cost delivered at the plants and ranged from 8 cents to 13 cents per gallon of distillate in various parts of the valley. In the lower part of the table under the same columns the electric power consumed at motor-driven plants is shown. In general these plants were not provided with meters and no means for testing power consumption were available. The results shown, therefore, are taken in most instances from power companies' bills. It is the custom of the power companies to test the plants from one to three times during the irrigation season and to charge for power used on the basis of the maximum amount consumed during their tests.

The figures of the building cost represent the cost of the completed pumping plants. The total costs are based on the most reliable information obtainable, including statements of owners and of the companies installing the machinery. From these total costs the cost per acre with maximum draft of 1 second-foot to 80 acres and the cost per acre irrigated in 1910 are obtained from the corresponding columns of the area irrigable.

The annual cost of depreciation, renewals, and repairs is based on the assumption that for a distillate plant these costs will amount to 15 per cent per year on the cost of the machinery and for a motor-driven plant to 8 per cent per year on the cost of the machinery. These values, if anything, are lower than the actual and do not depend very largely on the amount of use given the plant during the year, for the depreciation of machinery may be as great during periods of nonuse as during periods of use; in other words a plant may "rust out" as quickly as it would "wear out." There is of course a considerable variation in the sum total represented by the three items, depending on the care given to the machinery. In order to make a comparison of the various plants, however, a uniform percentage was used throughout, though the actual cost of all the machinery was not exactly that recorded in the notes on the tests. The item of taxes was not included with the other fixed charges, since a reliable

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value to be applied was not determined upon, but in other similar studies taxes have been figured as a per cent per year on the first cost.[1] Interest on the investment, another element of fixed charges, in the amount of 6 to 8 per cent on the first cost is also omitted from the items in the table.

In computing the annual cost of fuel (or current), labor, and lubrication, the fuel or current cost for the first column—involving 80 per cent continuous operation—is obtained from the figures of length of irrigation season in days and the fuel or current cost per 24 hours. For the fuel or current cost with operation as in 1910, the figures of continuous equivalent operation in days in 1910 and the fuel or current cost per 24 hours are used. To the costs of fuel alone thus obtained, 2 cents per hour of operation for distillate plants, 5 cents per hour for the steam plant, and 1 cent for motor-driven plants was added in order to cover the charges of labor and lubrication.

The figures of total annual cost of maintenance and operation are obtained from preceding data. The total costs are in each case the sum of the annual cost of fuel (or current), labor, lubrication, depreciation, renewals, and repairs. As has been previously stated, the items of taxes and interest on investment have not been included, but they probably would add an annual sum equal to about 7 to 9 per cent of the total building cost. The costs per acre are these total costs divided by the appropriate values for the area irrigable or irrigated. The costs per acre-foot of water pumped represent the total costs divided by the capacity of the plant in acre-feet per season. The total cost per acre-foot of water per foot of static head is the total cost per acre-foot of water pumped, divided by the static head.

The last column indicates the relative efficiency of the plants in percentages. To determine the figures in this column it was assumed that a gallon of distillate should produce 8 horsepower hours of energy in a plant of fairly good design. A comparison on this basis of the amount of fuel oil used with the useful water horsepower developed gives the efficiency. For example, in plant No. 1, 0.96 gallon of distillate per hour yielded 1.68 useful water horsepower, but on the basis of 1 gallon of distillate per hour to 8 useful water horsepower 0.96 gallon should yield 7.68 horsepower. The efficiency is therefore 1.68 divided by 7.68, or 22 per cent. For the steam plant it was assumed that 1 gallon of crude oil should produce 2.5 horsepower. Similarly, for motor-driven plants, comparison of the horsepower of electric energy used or paid for with the useful water horsepower developed gives the efficiency.

[1] Smith, G. E. P., Ground-water supply and irrigation in the Rillito Valley: Arizona Univ. Agr. Exper. Sta. Bull. 64, p. 209, 1910.

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SUMMARY OF PUMPING TESTS.

The irrigator is sometimes apt to consider only the actual expen of operation of a plant when figuring on the cost of pumping wa The cost of irrigation by pumping, however, includes properly b the cost of operation and all fixed charges, such as interest on investment, depreciation, taxes, and repairs.

In the descriptions of the individual pumping plants tested, att tion has in several instances been called to one or more of the spec factors that render the plant a relatively expensive source of wa supply. In summarizing the results of the tests these factors m properly be mentioned again and their effects on the cost of irrigat emphasized.

Most of the pumping plants in San Joaquin Valley are well hous but this important matter is not always properly attended to. rapid depreciation of pumping as well as other kinds of farm machin if not taken care of is very real, and depreciation is an import factor in the cost of irrigation water obtained from wells.

In the tabulated results of pumping tests the depreciation cha has been combined with those for renewals and repairs, the total the three being taken as 15 per cent per year for distillate pla and 8 per cent per year for motor-driven plants. These figures believed to be conservative, since in similar tests by others the dep ciation charge alone for gasoline plants has been taken as from to 12 or 15 per cent and for motor-driven plants as from 6 to 7 o per cent.[1] It will be noted that in the tabulated data summariz the tests in San Joaquin Valley, interest and taxes have not b included with the other fixed charges. They probably should taken as adding to these charges about 7 to 9 per cent per year the value of the plant.

The tendency throughout the valley is to install pumping machine capable of more work than is required of it. This custom may in part attributable to the sellers of the machinery, who are of cour desirous of making large sales; but the installation of large plan appears also to be followed as a matter of convenience in operatio The irrigator finds it easier to run a large pumping unit for a fe hours than to accomplish the same amount of irrigation with a small plant requiring perhaps several days to supply the same acreage wi water. The interest on the greater amount of capital tied up in t larger plant and the increased amount that must be charged to depr ciation form very considerable items in the total annual cost of irri gation, however. In places where a larger plant has been installed

[1] Le Conte, J. N., and Tait, C. E., Mechanical tests of pumping plants in California: U. S. Dept. Agr. Office Exper. Sta. Bull. 181, pp. 51–52, 1907.

Smith, G. E. P., Ground-water supply and irrigation in the Rillito Valley: Arizona Univ. Agr. Exper. Sta. Bull. 64, p. 209, 1910.

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Annual cost of depreciation, renewals, and repairs.
$48
54
49
96
115
128
64
153
81
100
200
37
100
39
180
96
81
210
250
350
98
285
25
60
105
100
460
450
40
16
128
40
130
80
20
20
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60
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50
190
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than is needed to supply the acreage watered the error can of course be remedied if more land can be furnished with water. The same result will of course be accomplished either by bringing new land under irrigation or by supplying from one plant lands that have been watered by two or more pumping units each of which has been operated only a small part of the time. The advantage of cooperation in reducing the cost per acre of irrigation is shown in the plants listed as tests Nos. 31 and 35.

Although theoretically the pumping system might be only large enough to furnish the necessary amount of water if kept running continuously throughout the irrigation season, practically the minimum size of plant is approximately fixed by the necessity of pumping a stream large enough to flow through the irrigation ditches with sufficient velocity to permit its proper distribution. From the observations made in San Joaquin Valley it would appear that in this region plants of less than 5 horsepower are not efficient in this respect, except perhaps in the case of plants used for watering small truck gardens. The size of stream that must be thrown in order to give proper distribution depends very largely on the character of the soil, however. In Sacramento Valley it has been found that "a discharge of at least 12 gallons a minute to the acre should if possible be provided for alfalfa on ordinary loam soils in tracts of 40 to 200 acres, with larger capacities for smaller tracts, and slightly smaller capacities for larger tracts."[1]

Although in some regions economy is obtained by the use of smaller plants pumping into reservoirs from which a sufficient discharge can be maintained during periods of irrigation, this practice has not been followed in the San Joaquin, and the cost of reservoir construction probably would more than counterbalance the saving in cost of pumping equipment under the conditions of irrigation that obtain.

In localities where pumping plants are installed as auxiliaries to surface water supplies the adaptation of proper size of plant to the area irrigated can not be adhered to; for in such instances a relatively large amount of water may need to be pumped during intervals of shortage in the ditch supply, and machinery capable of furnishing a given quantity of water in a limited time may be required. Such conditions obtain mainly in places where high-class crops are raised, however, which can profitably bear the relatively high cost per acre of pumping water. An example of this is furnished in the plant of W. E. Bunker (No. 15).

In connection with the mistake of installing a larger plant than is needed for the area irrigated may be mentioned the installation of a plant having greater pumping capacity than the well can supply.

[1] Bryan, Kirk, Ground water for irrigation in the Sacramento Valley, Cal.: U. S. Geol. Survey Water-Supply Paper 375-A, p. 38, 1915.

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Considerable loss in efficiency may develop in such cases, either simply from excessive draw down, which makes the pumping lift greater than need be, or from the entrance of air into the pump, whose suction is thereby impaired. Losses of efficiency directly traceable to leakage of air were noted in tests Nos. 8 and 39. Such overtaxing can usually be overcome by enlarging the well or by sinking one or more auxiliary wells connected by tunnels or by suction pipes to the pump intake.

Although pumps in good condition may lift water about 28 feet under suction, a lift of about 20 feet has been found in practice to be the maximum economical limit. Centrifugal pumps and the cylinders of reciprocating pumps should therefore be placed not higher than this distance above the water level when pumping. Examples of low efficiency produced in part at least by excessive suction lifts are furnished by plants Nos. 8, 21, and 30. Enlargements or bell-mouths on the ends of intake and discharge pipes are found to reduce the friction loss of head at entrance and discharge points and thus slightly to increase the efficiency. Likewise, the elimination of unnecessary elbows and bends in the pipes reduces friction losses. Cases where actual obstructions in pipes appeared to be responsible in part for the low efficiency were noted in plants Nos. 51 and 55.

At many pumping plants the end of the discharge pipe is placed higher than is necessary. Since every foot in height that the water is raised requires a certain amount of work, it is obvious that the discharge point should be only high enough to deliver the water into the ditch. Flagrant cases of disregard of this principle were not observed in the San Joaquin, however.

The running of a large internal combustion engine at less than its load capacity is an important factor in increasing pumping costs. Under such conditions, in order to keep down to normal speed, the engine misses a number of explosions each minute. Serious loss in efficiency may thus be occasioned, as brake tests show that under such conditions there is a marked loss in the effective work. This loss is due largely to the fact that the power consumed within the machine in compression of the charge and in friction losses is approximately constant, and hence as the amount of work produced by the machine is decreased the energy consumed internally becomes a larger portion of the total amount.[1] An especially noteworthy instance of low efficiency due to a poorly designed plant was found in that of T. R. Hill (test No. 1). The overloading of an engine, when normal speed is kept up by feeding an extra amount of fuel, is also uneconomical, both because of the excessive fuel consumption and the strain on the machinery.

[1] Le Conte, J. N., and Tait, C. E., Mechanical tests of pumping plants in California: U. S. Dept. Agr. Office Exper. Sta. Bull. 181, p. 72, 1907.

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Notable variations in speed, either of increase or of decrease beyond the normal, result in inefficient service; for every properly constructed engine is designed to run under conditions of speed and load that are fairly well determined by the size of the engine parts, and any great variation in these conditions is bound to be attended by loss in efficiency from one or more causes. In electric motors underspeeding does not result in notable efficiency loss since the internal friction losses are slight and a large part (80 to 90 per cent) of the power consumed is given out as useful work. Overspeeding, however, may necessitate repairs due to the overheating or burning out of parts.

The proper adjustment of feed and ignition in an internal combustion engine have very great influence on the efficient working of the machine. If the ignition is retarded too much, an excessive fuel charge is required. By advancing the spark, therefore, to produce a certain amount of preignition, the fuel consumption may be cut down appreciably. The improper timing of ignition may have been the cause of excess fuel consumption in plants Nos. 18, 19, and 28.

The temperature of the jacket water is a factor that is too often overlooked; for if the cylinder is cooled too much, ignition may lag, and the same effect will be produced as by a spark too far retarded.

Too little attention is in many cases paid to the proper oiling and adjustment of the various bearings. Injury of course may quickly result to them from overheating due to lack of oil, or to running too tight, while if too much play is allowed the engine will become injured by pounding. Slippage of a loose belt is often the cause of poor service, as in tests Nos. 13 and 40, while too tight a belt produces an undue strain on the pulley bearings.

For proper running of a pump, relations of load and speed similar to those in an engine must be taken into consideration. The improper speeding of a centrifugal pump will cause loss in efficiency because if underspeeded the runner will not impart an economic proportion of its velocity to the water, and therefore the pump will not lift water to its full capacity (tests Nos. 1 and 27); or, because if overspeeded, the runners will churn or will produce excessive velocity in the stream of water, with consequent losses due to excessive friction in the intake and outlet pipes (test No. 5). While a centrifugal pump throws more water when somewhat overspeeded, it requires much more power for a given discharge than does a larger pump run at the proper speed. As has been previously mentioned, overspeeding may also cause marked drop in efficiency by drawing air into the pump and impairing its suction. Overspeeding is, however, less to be avoided than underspeeding, since the discharge drops rapidly with slower rotation.

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For each rotary pump there is a definite relation between the lift of the water and the speed of the pump, for greatest efficiency. The proper speed for each lift is usually given by the pump maker, and should be closely adhered to for satisfactory results both in the amount of water lifted and in power economy.

In reciprocating pumps underspeeding may in some cases produce undue diminishing of the discharge through failure of the valves to open and close promptly. Overspeeding often results in the breaking of sucker rods or the loosening of pump foundations, with consequent throwing out of alignment and increased friction losses.

The proper size and speed for the pump will be determined by the amount of water to be discharged and the lift. The engine or motor should then be adapted in size to give the necessary power. By means of the proper-sized pulleys or gears the suitable working speed for both pump and prime mover can be obtained. The proper size of prime mover and pump for given lifts and discharge are given in some manufacturers' catalogues or will be supplied by the service departments of the firms. Consultation with these departments will often prevent costly mistakes in the installation of a plant. For the larger plants special design to suit the conditions of operation will generally be profitable. The following tables may be of use in some cases, however, in aiding in the choice of a suitable combination of prime mover and pump.

TABLE 35.—*Time required for irrigation with pumps of various sizes, assuming 3 acre-feet as duty of water per acre per annum.*

Area to be irrigated.	Water required per annum.	Time required for pump to raise tabulated quantities of water.[a]							
		3-inch pump, capacity 225 gallons per minute.	3½-inch pump, capacity 300 gallons per minute.	4-inch pump, capacity 400 gallons per minute.	5-inch pump, capacity 700 gallons per minute.	6-inch pump, capacity 900 gallons per minute.	7-inch pump, capacity 1,200 gallons per minute.	8-inch pump, capacity 1,600 gallons per minute.	10-inch pump, capacity 3,000 gallons per minute.
Acres.	*Acre-feet.*	*Hours.*	*Hours.*	*Hours.*	*Hours.*	*Hours.*	*Hours.*	*Hours.*	*Hours.*
5	15	360							
10	30	720	542						
15	45	1,080	814	610					
20	60	1,420	1,080	814					
30	90	2,160	1,630	1,220	697	542			
40	120	2,880	2,170	1,630	930	723	542		
60	180	4,320	3,260	2,440	1,400	1,080	814	610	
80	240		4,340	3,260	1,860	1,440	1,080	814	
100	300			4,070	2,320	1,810	1,360	1,020	542
120	360			4,880	2,790	2,170	1,630	1,220	650
160	480				3,720	2,890	2,170	1,630	868
200	600				4,650	3,620	2,710	2,030	1,080
240	720					4,340	3,260	2,440	1,300
280	840					5,060	3,800	2,850	1,520
320	960						4,340	3,260	1,730
360	1,080						4,880	3,660	1,950
400	1,200							4,070	2,170
480	1,440							4,880	2,600
560	1,680								3,040
640	1,920								3,470
760	2,280								4,120
880	2,640								4,770

[a] Capacities taken from manufacturers' catalogues.

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TABLE 36.—*Engine horsepower, cost of pumping plant, annual fixed charges, and cost per hour of operation for pumps operated against various static heads.*[a]

Static head.	Size of pump.	Engine horse-power.	Cost of pumping plant.	Annual fixed charges.	Cost per hour of operation.
Feet.	*Inches.*				*Cents.*
20	3	3	$300	$59	6.7
	3½	4	360	72	7.6
	4	5	420	85	9.1
	5	8	600	125	11.9
	6	10	770	162	13.4
	7	15	1,050	218	17.2
	8	20	1,320	274	22.2
	10	35	1,920	398	39.9
25	3	4	350	70	7.3
	3½	5	410	83	8.6
	4	6	480	99	10.1
	5	10	720	149	13.1
	6	15	990	205	16.2
	7	18	1,150	238	20.9
	8	25	1,480	307	27.3
	10	45	2,250	467	49.3
30	3	4	360	71	8.3
	3½	6	470	95	9.3
	4	8	590	121	10.5
	5	12	840	173	15.3
	6	18	1,110	229	18.8
	7	20	1,280	264	24.7
	8	30	1,660	343	32.4
	10	50	2,430	502	58.8
35	3	5	420	83	9.0
	3½	6	480	96	10.5
	4	8	600	122	11.9
	5	15	960	197	17.5
	6	18	1,120	230	21.9
	7	25	1,450	298	28.5
	8	35	1,840	379	37.4
	10	60	2,660	549	68.3
40	3	6	480	94	9.3
	3½	8	600	121	10.5
	4	10	720	146	12.1
	5	18	1,080	220	19.7
	6	20	1,230	251	24.7
	7	30	1,620	332	32.3
	8	40	2,010	413	42.4
	10	75	3,000	618	77.8
45	3	6	530	104	10.2
	3½	8	660	132	11.5
	4	10	790	159	13.4
	5	18	1,170	238	21.9
	6	25	1,500	306	27.6
	7	30	1,740	356	36.1
	8	45	2,300	472	47.5
	10	75	3,170	649	87.2
50	3	8	640	126	10.0
	3½	10	780	155	11.5
	4	12	910	182	14.6
	5	20	1,290	261	24.1
	6	25	1,510	307	30.4
	7	35	1,920	392	39.9
	8	50	2,470	506	52.5
	10	100	3,760	773	96.5
55	3	8	650	127	10.8
	3½	10	790	156	12.4
	4	15	1,030	206	15.9
	5	25	1,460	295	26.3
	6	30	1,690	343	33.3
	7	40	2,100	428	43.7
	8	50	2,480	507	57.8
	10	100	3,770	774	106.0
60	3	8	660	128	11.5
	3½	10	800	157	13.4
	4	15	1,040	207	17.2
	5	25	1,470	296	28.5
	6	30	1,700	344	36.1
	7	45	2,270	462	47.5
	8	60	2,710	553	62.8
	10	100	3,780	775	116.0

[a] Cost of pumping plant is exclusive of wells and casing. Fixed charges are 8 per cent of cost of pumping plant plus 14 per cent of cost of machinery. Cost of operation is cost of fuel at 10 cents a gallon plus 2 cents an hour for labor and lubrication.

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From the average rated capacity for each size of pump, obtained from manufacturers' catalogues (Table 35), and the lift, the necessary water horsepower is obtained from the formula given on page 165, which may be a little more simply expressed thus:

$$\text{Useful water horsepower} = \frac{\text{Total static head in feet} \times \text{discharge in gallons per minute}}{3{,}957}$$

A plant efficiency of about 43 per cent, determined mainly from experimental tests of good plants, has been applied to these values of water horsepower to obtain the figures of required engine horsepower for Table 36, the nearest standard size of engine above the required horsepower being taken in nearly every case. The sizes of engine needed are larger than those given in similar tables in catalogues of pumping machinery; but they are believed, from results observed in actual experience, to be approximately correct.

The cost of pumping plant includes only the cost of engine, pump and fittings, and the housing. Since the cost of engine and pump varies somewhat according to the make and the cost of housing varies with the style of building used, the three items have been combined into the averages presented. The prices used for the machinery, however, are average list prices for the indicated sizes of distillate engines and centrifugal pumps, and the cost of housing is based on actual examples. This latter item is taken as about $50 for the smaller plants, increasing for the larger sizes by about 10 per cent of the additional cost of the machinery. Attempt has not been made to determine the average cost of well and casing, since these are such variable quantities that averages would be of no special significance. In some places the cost of the completed well is relatively small, while in other places it may equal the cost of the remainder of the plant.

The annual fixed charges have been computed as 8 per cent of the cost of pumping plant plus 14 per cent of the estimated cost of engine and pump alone. While this is a somewhat different basis of estimate from that used in calculating the fixed charges of Table 34, and includes allowance for interest and taxes, it is believed to be fair and to give approximately the same results.

The cost per hour of operation is based on the probable amount of distillate used per hour, at 10 cents per gallon, plus 2 cents per hour of operation for labor and lubrication. The duty of distillate is taken, as the result of numerous tests, at one-eighth gallon per horsepower per hour developed. In the table this is of course not the same as the horsepower "size" of the engine, which is adapted only approximately to the actual power required. The hourly consumption of distillate for each combination of pump and lift can be obtained, if desired, from the last column, by subtracting the labor

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and lubrication cost (2 cents) and dividing by 10 (the assumed price in cents per gallon). For example, in the first case the computed distillate consumption is 0.47 gallon per hour. From this figure other calculations based on different costs per gallon can be made.

Example.—It is desired to irrigate by pumping a tract of 80 acres of land to be set in alfalfa. In consideration of rainfall, evaporation, and other climatic conditions the area should be flooded during the irrigation season with sufficient water in amount to cover the land 3 feet in depth (equivalent to flooding 6 inches in depth six times during the season). The depth to water in neighboring wells is about 20 feet, and it is desired to raise the water 5 feet above the surface of the ground at the proposed pumping plant. The irrigation season is about 200 days in length.

Referring to Table 35, opposite 80 in the first column, we find that a 3½-inch pump will require 4,340 hours, or 21.7 hours a day for 200 days to supply the desired amount of irrigating water; a 4-inch pump will require 3,260 hours, or 16.3 hours a day for 200 days; a 5-inch pump will require 1,860 hours, or 9.3 hours a day for 200 days; a 6-inch pump will require 1,440 hours, or 7.2 hours a day for 200 days, etc. Now, the depth to water being 20 feet and the lift above the surface of the ground 5 feet, a head of 25 feet must be provided for in addition to the suction lift. The suction lift should be taken at 25 feet unless it be known that a well of great capacity can be secured. The total static head, therefore, in this case will be 50 feet. In the table on page 173, opposite "50" in the column for static head, the following information can be found:

a. 3½-inch pump, 10-horsepower engine, cost, with housing, $780:	
Fixed charges	$155
Operation, 4,340 hours at 11.5 cents per hour	499
Total yearly cost of pumping	654
Yearly cost per acre	8.18
b. 4-inch pump, 12-horsepower engine, cost, with housing, $910:	
Fixed charges	182
Operation, 3,260 hours at 14.6 cents per hour	476
Total yearly cost of pumping	658
Yearly cost per acre	8.22
c. 5-inch pump, 20-horsepower engine, cost, with housing, $1,290:	
Fixed charges	261
Operation, 1,860 hours at 24.1 cents per hour	448
Total yearly cost of pumping	709
Yearly cost per acre	8.86
d. 6-inch pump, 25-horsepower engine, cost, with housing, $1,510:	
Fixed charges	307
Operation, 1,440 hours at 30.4 cents per hour	438
Total yearly cost of pumping	745
Yearly cost per acre	9.31

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c. 7-inch pump, 35-horsepower engine, cost, with housing, $1,920:

Fixed charges	392
Operation, 1,080 hours at 39.9 cents per hour	431
Total yearly cost of pumping	823
Yearly cost per acre	10.29

. It appears from these figures that the total cost of pumping gradually increases with the size of plant used. This is because the larger plants lie idle a proportionately greater time, while interest, taxes, depreciation, etc., accumulate. With the foregoing information in mind, the rancher can proceed to have a well, or wells, bored with some definite idea of the sort of plant he will need. The boring, digging, or drilling of wells in such manner as to secure the greatest flow of water at least cost is a matter subject to wide variation in procedure in accordance with local conditions. Let it be assumed that a well is bored and the test [1] shows a flow of 300 gallons a minute with a lowering of 15 feet in the water surface. Such a well will supply a 3½-inch pump with a suction lift of 15 feet (assuming the pump to be placed at the water surface); a 4-inch pump with a suction lift of about 20 feet; but will not supply a pump of larger size. With this well, therefore, the choice is narrowed down to plants *a* and *b*. It is now possible to revise the estimates because, instead of a suction lift of 25 feet, as previously assumed, it is known that the lift will be about 15 feet for plant *a*, or 20 feet for plant *b*. The total static heads will be 40 feet and 45 feet, respectively. From Table 36 the following revised estimates are derived:

a–1. 40-foot head, 3½-inch pump, 8-horsepower engine, cost, with housing, $600:

Fixed charges	$121
Operation, 4,340 hours at 10.5 cents per hour	456
Total yearly cost of pumping	577
Yearly cost per acre	7.21

b–1. 45-foot head, 4-inch pump, 10-horsepower engine, cost, with housing, $790:

Fixed charges	159
Operation, 3,260 hours at 13.4 cents per hour	437
Total yearly cost of pumping	596
Yearly cost per acre	7.45

It is seen that plant *b*–1 costs $190 more than plant *a*–1 and that the yearly cost of pumping will be $19 greater. In view of the lesser time required for pumping, the larger plant would probably be chosen by most ranchers, but with the foregoing study of the problem, the choice could be made intelligently with clear knowledge as to what the added convenience of the larger plant will cost. If a still larger plant were, for any reason, considered desirable additional wells would be required.

[1] Every well should be carefully tested by pumping and its flow measured before a pumping plant is purchased. Only in this way can the plant purchased be adapted to the flow obtainable from wells.

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COUNTY NOTES.

By W. C. MENDENHALL and R. B. DOLE.

SAN JOAQUIN COUNTY.

GENERAL CONDITIONS.

San Joaquin County is, with the exception of small areas in Alameda and Contra Costa, the northernmost of those counties whose valley lands belong to the southern division of the great central lowland of California. Because of its latitude and its position near the gateway that opens to the Pacific, it differs greatly climatically from the southern counties of the valley. Its temperatures are not so high and do not fluctuate through so wide range (monthly averages vary from 46.5° in January to 72.5° in July and August), its rainfall is greater, amounting to about 15.5 inches, and its percentage of foggy days exceeds that of Kern, Tulare, and other of the southern counties. Furthermore, situated as it is along the lower San Joaquin, it includes a tidal section of that stream and a large area, called Stockton Islands, that is subject to inundation when the Sacramento is in flood, and a still larger section subject to overflow, except where it is protected by dikes and levees, when floods in the San Joaquin and its tributaries occur at the same time as those of the Sacramento. The county, therefore, includes a part of that central California area, whose problems of reclamation, drainage, and navigation involve in so complete and fascinating a way all of the phases of hydraulic engineering. The rivers must be improved and controlled for navigation purposes, the lowlands must be protected from floods and drained, while the higher bordering parts of the valley lands, too dry to produce the more valuable crops although suited to grain raising, require irrigation for their fullest development. This threefold problem belongs typically to the Sacramento Valley, but it requires solution also in that of the lower San Joaquin.

The Stanislaus Water Co. takes its supply of water from the Stanislaus near Knights Ferry and irrigates an area of several thousand acres along the southern border of the county in the Escalon and Manteca districts. In the Lodi and Stockton districts the systems of the Stockton & Mokelumne Irrigating Co. and the Woodbridge Canal & Irrigation Co. supply surface waters to limited areas. Within the island district, west and north of Stockton, where reclamation has been accomplished by the construction of protective levees, water is

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sometimes admitted within the dikes during high-water periods in the streams for irrigation purposes, but as subirrigation is effectual throughout the greater part of these areas, surface irrigation is rarely necessary.

The higher lands of the valley slopes, both along the east and west sides, are devoted to grain raising, as some of them have been for almost half a century. No water is applied to them. There is no uniformity as to practice among the vineyardists, some of them irrigating their vines, others preferring that they be not irrigated.

FLOWING WELLS.

San Joaquin County includes the northern portion of the great central artesian zone of the valley, but as this zone is less important in its northern part, both because of the inferior yield of wells there and because of the greater proportion of water of poor quality obtained from them, there has been relatively little development for irrigation purposes or domestic supply. Twenty-nine records have been obtained, and these are believed to include all of the flowing wells existing in the country districts and nearly all of those in the city of Stockton at the time when the records were secured. Only six of these supply water suitable for irrigation, and the yield of these is small. By far the greater number of the flowing wells have been drilled for the gas they yield, but as the water with the gas is saline and therefore not usable for drinking or for irrigation it is allowed to waste.

The few artesian wells that furnish water of good quality not only yield small supplies but are expensive because of their considerable depth. Those of which records are available are from 975 to 1,200 feet deep. Wells of lesser depth do not yield flows, and those of greater depth, at least in the Stockton neighborhood, yield saline waters and gas. Farther west than Stockton, nearer the axis of the valley, the water, even from shallow wells, is strongly mineralized. It will be realized that under these conditions flowing wells are not of value for irrigation in the county, despite the rather large area over which flows may be obtained.

PUMPING PLANTS.

During the last few years irrigation by the use of pumped waters has become an important factor in the development of the east side of San Joaquin County. Around Lathrop and French Camp in the district east of Stockton and in the country about Lodi, a large number of plants have been installed and new wells are being sunk and new plants put in operation constantly.

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This development is of a most promising type. Most of the plants are small and the acreage irrigated by each is limited. This means small holdings, intensive cultivation, and eventually relatively dense settlement. The average recorded horsepower of 193 plants is only 6.2. Of the 193 plants 138 develop from 2 to 8 horsepower, while 42 are equipped with engines developing from 10 to 15 horsepower. One hundred and eighty-seven gas engines were in use in 1906, 13 plants used motors at that time, and 2 were operated by steam.

One hundred and thirty-seven owners of plants reported a total of 1,455 acres under irrigation, an average of only 10.6 acres each. The cost of 106 of the plants was reported by the owners as $64,983, an average cost of $613 each. These facts indicate the small scale and individualistic character of the development.

The power companies charge a uniform rate of 3½ cents per horsepower per hour. This is higher than the fuel charge in the gas plants, the reported average in 12 plants for the summer of 1906 being 1.45 cents per horsepower per hour, but labor and installation, both of which are heavier charges in the gas plants, tend to equalize the difference. Water as developed in these small plants seems to cost the users from $1.50 to as much as $3 or $4 per acre-foot.

Generally water is delivered from the pumping plants to the acreage served through earth ditches, and where the soil is sandy and porous this method results in much waste.

The pumping-plant wells are comparatively shallow, and hence are very much cheaper than the deep wells necessary to secure artesian flows. The average depth of somewhat more than 100 wells, taken at random from the records, is about 80 feet. Another group of 20 wells average only 40 feet in depth. These latter wells are equipped with small pumping plants, developing an average of 5 horsepower each, and the water which they yield is ample.

The wells are particularly cheap because it has been found that in many parts of the area it is not necessary to case them, or at least they need be cased only to slight depths. Twelve pumping-plant wells are reported as without any casing; 24 others were only partly cased, the pipe in these varying in length from a few joints to three-fourths or seven-eighths of the entire depth of the well.

The windmill has been an important factor in irrigation in the Stockton district, and although it has been practically superseded by the small pumping plant, it is still used, especially in the vegetable garden and fruit districts east and northeast of Stockton. Its chief disadvantage, of course, is the uncertainty of the wind. It is not unusual to see a well equipped both with a small gas engine and a large windmill, the engine being used when the wind fails. The wheels used are of wood and of local manufacture, from 18 to 22 feet in diameter, and cost complete with the tower from $175 to $200.

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Much of the gardening and fruit for the San Francisco market is in the hands of Italian immigrants, who, after giving the windmill a thorough trial, have generally abandoned it in favor of the more reliable gas engine.

Irrigation by pumping, of the general type practiced about Stockton and Lodi, could be extended with great advantage throughout a large acreage, now without water, between Mokelumne River and Tejon Pass, but to be practiced successfully it will require a different spirit from that which as yet largely dominates the West. The promoting and speculative spirit, the desire to get rich overnight, to control large holdings, and to avoid personal labor, will have to be superseded by a willingness to be satisfied with sure but moderate returns, to be content with small farm units, and to attain personal independence through individual effort. It is to be hoped that the American citizen of the generations to come will prove willing to accept these conditions and that in the future dependence need not be placed upon our adopted citizens for detailed development of this desirable type.

QUALITY OF WATER.

The waters that were tested from wells 20 to 40 feet deep on the east side of San Joaquin County contain somewhat greater quantities of all mineral constituents than those from wells 50 to 1,100 feet deep, and though they are low in alkalies and are good for irrigation they are rather poor for steaming because of their content of scale-forming matter. Water from wells 50 to 900 feet deep is commonly the best. Wells around Stockton 900 to 1,100 feet deep yield water somewhat higher in sodium and potassium than in calcium and magnesium and therefore poorer for irrigation; this characteristic content of alkali probably decreases, however, toward the Sierra. Waters from depths greater than 1,100 feet around Stockton are unfit for use because they are salty, and that condition probably is uniform over the entire county.

No ground waters among Stockton Islands could be tested, but according to common report they are bad, which doubtless means that they are highly mineralized calcium sulphate or sodium sulphate waters with appreciable amounts of chlorides. This would make them bad for boilers and poor for irrigation.

The waters of T. 2 S., R. 4 E., are higher in mineral content and poorer for irrigation than those farther east, and many are of the calcium sulphate type. Around Tracy and Banta wells more than 100 feet deep yield better water than shallower ones. The change to waters of the axial type, or those in which the alkalies exceed the alkaline earths, is apparently complete within the limits of El Pescadero, where the waters that were tested are suitable for irrigation. Water

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			tion.	
High.....	$Na\text{-}SO_4$....	Bad.....	Fair...	Southern Pacific Co.
..do.....	$Ca\text{-}SO_4$....	...do.....	...do...	Pacific Coast Oil Co.
Moderate..	$Na\text{-}SO_4$....	Poor.....	Good..	Southern Pacific Co.
...do.....	$Ca\text{-}SO_4$....	...do.....	...do...	Do.
Low.....	$Ca\text{-}CO_3$....	Fair.....	...do...	Do.
Moderate..	...do.....	...do.....	...do...	Do.
..do.....	...do.....	...do.....	...do...	F. M. Eaton.
..do.....	...do.....	...do.....	...do...	Southern Pacific Co.
..do.....	...do.....	...do.....	...do...	F. M. Eaton.
..do.....	...do.....	...do.....	...do...	Do.
Very high.	Na-Cl.....	Very bad..	Bad...	Do.
Moderate..	$Na\text{-}CO_3$...	Poor.....	Fair...	Kennicott Water Softener Co.
..do.....	...do.....	Fair.....	...do...	Walton Van Winkle.
..do.....	...do.....	...do.....	...do...	F. M. Eaton.
..do.....	...do.....	...do.....	...do...	D. B. Bisbee.
..do.....	$Ca\text{-}CO_3$....	...do.....	Good..	Southern Pacific Co.
..do.....	...do.....	...do.....	...do...	F. M. Eaton.
..do.....	...do.....	Poor.....	...do...	Southern Pacific Co.
..do.....	...do.....	...do.....	Fair...	Do.
..do.....	...do.....	Fair.....	Good..	Do.
..do.....	...do.....	...do.....	...do...	F. M. Eaton.
..do.....	...do.....	...do.....	...do...	Kennicott Water Softener Co.

deep.
umping station.
00 feet deep.
,000 feet deep.

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from wells 100 to 500 feet deep in the territory from El Pescadero to within 2 or 3 miles of the foothills could probably be applied to crops without harm if proper drainage were arranged, but water from wells more than 500 feet deep would probably be no better than that from shallower ones.

Though the water of San Joaquin River is altered in quality by the combined effects of ground affluents from the upper west side, seepage from irrigated lands on the east side, and occasional influxes of water from west-side creeks, it is usually low in mineral content and fairly clear, and at all times good for irrigation as the analyses made by the Geological Survey for two years establish.

The results of analyses and assays of ground waters in San Joaquin County are given in Tables 37 and 38, in which the waters have also been classified with respect to their value for domestic and boiler use and for irrigation.

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WELL RECORDS.

The facts assembled in the following tables and in much of the preceding discussion were secured by W. N. White in 1906–7. Practically all of the pumping plants and all wells of importance then existing were examined and the essential data regarding them were secured. In addition enough of the shallow domestic wells in the outlying areas were examined to furnish evidence of the depth to ground water and to give some indication of its quality. Much more complete evidence on the latter point was procured by R. B. Dole in 1910 and has been assembled in the chapter and tables prepared by him and appearing both in the county notes and in the general discussion. Records of a few wells in Alameda, Calaveras, and Contra Costa counties are appended.

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TABLE 39.—*Records of wells in San Joaquin, Contra Costa, Calaveras, and Alameda counties.*

San Joaquin County.

Owner.	Location.	Year completed.	Type and diameter of well.	Depth of well.	Depth to water level.	Temperature of water.	Method of lift.	Use of water.[a]	Yield.	Cost of well.	Cost of machinery.
				Feet.	*Feet.*	° *F.*			*Miner's inches.*		
Lockeford village	Sec. 25, T. 4 N., R. 7 E.	1880?	Dug	60	42	.....	Gas	D	[b] 3	.....	$225
S. Parker	Sec. 36, T. 4 N., R. 7 E.	Old.	Bored, 7 inches	50	30	.....	Wind	D, S	.....	.....	.....
J. Ryan	Sec. 35, T. 4 N., R. 7 E.	1881?	Dug, 4 feet	42	31	.....	do	D, S	.....	.....	.....
D. J. Thomas	Sec. 5, T. 3 N., R. 8 E.	1887?	do	55	42	68	do	S	.....	.....	.....
C. L. Jones	Sec. 8, T. 3 N., R. 8 E.	1886	Bored, 7 inches	85	34	.....	do	D, S	.....	.....	.....
D. J. Thomas	Sec. 17, T. 3 N., R. 8 E.	1875?	Dug and bored	82	33	.....	do	D, S	.....	.....	.....
Peters estate	Sec. 20, T. 3 N., R. 8 E.	Old.	do	60	30	.....	do	D, S	.....	.....	.....
W. L. Irvin	Sec. 32, T. 3 N., R. 8 E.	1906	Bored, 8 inches	224	.....	.....	.....	.....	.....	.....	.....
Do	do	1906	do	200	29?	.....	Gas	I	.....	.....	1,800
Felix Faber	Sec. 3, T. 3 N., R. 7 E.	1904	Bored, 10 inches	50	24	.....	do	I	.....	$100.00	390
George Pressler	do	.....	do	75	22	.....	do	I	.....	.....	575
Peter Heil	Sec. 4, T. 3 N., R. 7 E.	.....	Bored	80	10	.....	do	I	[b] 75	100.00	600
L. M. Lewis	do	1904	Bored, 10 inches	86	22	.....	do	I	[b] 40	140.00	550
J. C. Kennison	Sec. 5, T. 3 N., R. 7 E.	1904	Bored, 12 inches	45	15	.....	do	I	.....	.....	[c] 575
P. Milloglav	do	1898	Dug and bored	46	15	.....	do	I	[b] 45	.....	[c]1,200
A. H. Boese	do	1904?	Bored, 10 inches	.....	15	.....	do	I	[b] 40	.....	425
H. D. Binger	do	.....	Bored, 8 inches	85	16	.....	do	I	.....	75.00	650
J. C. Theden	do	1902	Bored	35	18	.....	do	I	[b] 50	50.00	600
Mr. Olmar	Sec. 6, T. 3 N., R. 7 E.	.....	Bored, 8 inches	66	15	.....	Electric	I	.....	.....	.....
H. E. Taylor	do	.....	Bored, 4 inches	70	15	.....	do	I	[b] 17	.....	325
Henry Pope	do	1903	Bored, 10 inches	90	16	.....	do	I	.....	110.00	175
G. O. Thornton	do	.....	Bored, 8 inches	42	16	.....	Gas	I	[b] 55	.....	[c] 500
Levi Atwood	do	.....	Bored, 10 inches	32	10	.....	Electric	I	.....	.....	[c] 500
C. A. Black	do	1904	Bored, 8 inches	55?	12	.....	Gas	I	[b] 20	.....	400
Joe Williams	do	.....	do	40	9.9	66	do	I	.....	.....	425
Joseph Moran	do	.....	Bored, 12 inches	120	19	.....	Electrical	I	.....	.....	700
Carey Bros	Lodi	1904	Bored, 8 inches	160	16	.....	do	D	.....	.....	.....
Do	do	1904	do	160	16	.....	do	D	[b] 130	.....	.....
Mrs. J. L. Pearson	Sec. 13, T. 3 N., R. 6 E.	1904	Bored	85	13	66	Gas	I	.....	.....	500
M. C. Gammon	Sec. 12, T. 3 N., R. 6 E.	1902	Bored, 8 inches	44	4	.....	do	I	.....	.....	[c] 700
E. E. Durston	do	1907	Bored, 6 inches	40	6	.....	Electric	I	.....	50.00	300
Ida Hill	do	1904	Bored, 8 inches	40?	8	.....	Gas	I	.....	.....	[c] 300+
S. P. Howe	do	1904	Bored, 10 inches	80	8	.....	do	I	[b] 20	.....	285
Henry Adams	do	1906	.....	36	7	.....	Electric	I	.....	.....	300
N. F. Dethlefsen	do	1906	Bored, 6 inches	50	7	.....	do	I	.....	.....	[c] 300
Paul Sturla	do	1904	Bored, 8 inches	100	7	.....	Gas	I	[b] 55	.....	.....

[a] D, domestic; S, stock; I, irrigation; B, boilers; N, not used; R, roads. [b] Yield estimated or statement of owner taken. [c] Cost of well and equipment combined.

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TABLE 39.—*Records of wells in San Joaquin, Contra Costa, Calaveras, and Alameda counties*—Continued

San Joaquin County—Continued

Owner.	Location.	Year completed	Type and diameter of well.	Depth of well	Depth to water level	Temperature of water	Method of lift	Use of water	Yield	Cost of well	Cost of machinery
				Feet	*Feet*	*° F*			*Miners' inches*		
Edward Hutchins	Sec. 2, T. 3 N., R. 6 E.						Electric				
Mrs. D. E. Allison	Sec. 11, T. 3 N., R. 7 E.	1903		[illegible]	[illegible]	[illegible]	Gas		[illegible]		
C. D. Smith	Sec. 2, T. 3 N., R. 7 E.	1905	Dug and bored, 8 inches.	[illegible]	[illegible]		do				[illegible]
G. De Pauli	Sec. 11, T. 3 N., R. 7 E.			[illegible]	[illegible]		do				
T. B. Giffroy	do		Bored, 8 inches	[illegible]	[illegible]		Electric		[illegible]	[illegible]	[illegible]
Charles Kraft	Sec. 11, T. 3 N., R. 6 E.	1905	Bored, 10 inches	[illegible]	[illegible]		Gas			[illegible]	[illegible]
John Schiffler	do	1906	Bored, 6 inches	[illegible]	[illegible]		do				[illegible]
E. A. Beard	do	1905	Bored, 10 inches	[illegible]	[illegible]	[illegible]	do		[illegible]	[illegible]	[illegible]
H. A. Goodman	do			[illegible]	[illegible]		do				[illegible]
C. W. Fish	Sec. 12, T. 3 N., R. 6 E.	1906	Bored, 10 inches	[illegible]	[illegible]		do		[illegible]	[illegible]	[illegible]
Edward Powers	Sec. 10, T. 3 N., R. 6 E.	1904	do	[illegible]	[illegible]		do		[illegible]	[illegible]	[illegible]
James Clausen	Sec. 11, T. 3 N., R. 6 E.	1905	Bored	[illegible]	[illegible]		Electric				[illegible]
H. F. Beckman	do	1904	do	[illegible]	[illegible]		Gas				[illegible]
W. Hieb	Sec. 13, T. 3 N., R. 6 E.		Bored, 6 inches	[illegible]	[illegible]		do		[illegible]		[illegible]
H. Rinn	do	1904	Bored, 8 inches	[illegible]	[illegible]		do				[illegible]
Jacob Koening	do	1904	Bored, 10 inches	[illegible]	[illegible]		do		[illegible]	[illegible]	[illegible]
O. B. Morris	Sec. 18, T. 3 N., R. 7 E.	1905	Bored, 12 inches	[illegible]	[illegible]		do			[illegible]	[illegible]
P. H. Tindell	Sec. 16, T. 3 N., R. 7 E.	1909	Bored, 8 inches	[illegible]	[illegible]		do		[illegible]		[illegible]
Do	Sec. 18, T. 3 N., R. 7 E.	1906	Bored, 12 inches	[illegible]	[illegible]		Electric		[illegible]	[illegible]	[illegible]
J. F. Jungebruit	Sec. 7, T. 3 N., R. 7 E.	1904	Bored, 10 inches	[illegible]	[illegible]		Gas				[illegible]
Julius Woock	do	1906	Bored, 8 inches	[illegible]	[illegible]		do			[illegible]	[illegible]
J. B. Williams	Sec. 8, T. 3 N., R. 7 E.	1905	do	[illegible]	[illegible]		do		[illegible]		[illegible]
F. E. Hosmer	do	1904	Bored, 10 inches	[illegible]	[illegible]		do				[illegible]
G. A. Grimes	do	1902	Bored, 6 inches	[illegible]	[illegible]		do			[illegible]	[illegible]
O. Pool	do	1905	Bored, 10 inches	[illegible]	[illegible]		do			[illegible]	[illegible]
John Rohrbach	Sec. 17, T. 3 N., R. 7 E.	1906	do	[illegible]	[illegible]		do				[illegible]
Louis Dourin	Sec. 16, T. 3 N., R. 7 E.	1904	do	[illegible]	[illegible]		do		[illegible]		[illegible]
John Schmaidt	Sec. 9, T. 3 N., R. 7 E.	1902?	do	[illegible]	[illegible]		do		[illegible]	[illegible]	[illegible]
George Mettler	do	1905	do	[illegible]	[illegible]		do			[illegible]	[illegible]
J. Handel	do	1906	do	[illegible]	[illegible]	[illegible]	do			[illegible]	[illegible]
Charles Russ	do	1905	do	[illegible]	[illegible]		do				[illegible]
Fred Hieb	Sec. 15, T. 3 N., R. 7 E.	1905	Bored, 8 inches	[illegible]	[illegible]		do		[illegible]		[illegible]
F. J. Mettler	Sec. 22, T. 3 N., R. 7 E.	1904	Bored, 10 inches	[illegible]							
Do	do	1904	do	[illegible]	[illegible]		Gas				[illegible]
John Handel	Sec. 15, T. 3 N., R. 7 E.	1903	do		[illegible]		do				[illegible]
John Hieb	do	1905	do	[illegible]	[illegible]		do		[illegible]		[illegible]
G. Handel	Sec. 21, T. 3 N., R. 7 E.	1906	do	[illegible]	[illegible]		do				[illegible]

Fred Schmaidt	do	1906	do	110	13		do	I	[a] 75		[b] 720
L. W. Dye	Sec. 28, T. 3 N., R. 7 E.	1904	do	46	12		do	I		50.00	550
J. F. Loeffler	do	1902	do	95	12		do	I			600
G. J. Loeffler	Sec. 33, T. 3 N., R. 7 E.	1904	do	54							
Do	do	1904	do	14							
Do	do	1904	do	60	12		Gas	I	[a] 55		615
Mrs. Thomas Bunch	Sec. 31, T. 3 N., R. 7 E.	1905	do	136	14		do	I			725
J. C. Dutton	do	1906	do	60	12		do	I			[b] 600
Fred Sanguinetti	Sec. 30, T. 3 N., R. 7 E.	1903?	do	103	8		do	I			400
A. E. Pull	do		Bored, 7 inches	40	9		do	I			
A. S. Laselle	Sec. 25, T. 3 N., R. 6 E.	1904	Bored, 8 inches	90							
Do	do	1904	Bored, 10 inches	90							
Do	do	1904	Bored, 17 inches	218	8		Gas	I	[a] 70	350.00	800
Do	do	1906	Bored, 10 inches	26	4.5		do	I	[a] 20		500
Do	do	1902	do	124	8		do	I			[b] 625
George Welley	Sec. 30, T. 3 N., R. 7 E.	1906	do	88	10?		do	I			285
George Hogan	Sec. 19, T. 3 N., R. 7 E.	1905	Bored, 12 inches and 8 inches.	55	12		do	I	[a] 95		[b] 1,000
Dr. Haight	do	1903	Bored, 12 inches	65	12		do	I			784
Samuel Ferdun	do	1904	Bored, 12 inches and 3 inches.	115	12		do	I	[a] 125	22.50	
R. E. Ryan [c]	Sec. 24, T. 3 N., R. 6 E.	1904	Bored, 10 inches and 8 inches.	72	13		do	I		100.00	750
David McEvoy	do	1906	Bored, 12 inches	65	11		do	I	[a] 75	60.00	750
Fred Meyers	do	1904	do	50	8		do	I		50.00	750
A. S. Edlemann	do	1904	Bored, 10 inches	85	22		do	I			[b] 500
John Emde	Sec. 15, T. 3 N., R. 6 E.						do	I			
C. L. Boynton	do	1906	Bored	50?	8		do	I			[b] 300
Louis Keshman	Sec. 22, T. 3 N., R. 6 E.	1905?	Bored, 5 inches	37	4		do	D, S			
H. A. Mettler	Sec. 27, T. 3 N., R. 6 E.		Dug	20	8?		Wind	D, S			60
S. H. Eshley	Sec. 34, T. 3 N., R. 6 E.	1901?	Bored, 4 inches	33	4.3		do	D, S			85
E. G. Young	Sec. 4, T. 2 N., R. 6 E.	1901	Bored, 2½ inches	60	12		do	D, S			
George Mosher	Sec. 1, T. 3 N., R. 6 E.	1885?	Bored, 3 inches	75?	9		do	D, S			
Mrs. J. C. Swain	Sec. 12, T. 2 N., R. 6 E.	1891	Bored, 4 inches	180	7		do	D, S			60
W. J. Little	Sec. 10, T. 2 N., R. 6 E.	1888	Bored, 8 inches	1,165?	0	84	Artesian		[a] 9	3,000.00	
G. C. Swain	Sec. 15, T. 2 N., R. 6 E.	1899	Bored, 4 inches	112	8		Wind and gas	D, S			75
J. F. Dolan	Sec. 16, T. 2 N., R. 6 E.	1901	Bored, 3 inches	110	6.3		Wind	D, S		13.00	113
San Joaquin County	do	Old.	Bored, 6 inches	47	6.7		do	R			
J. C. Swain	Sec. 22, T. 2 N., R. 6 E.	1885?	Bored, 4 inches	100?	10.5		do	D, S		30.00	
California State Hospital for Insane	Campo de los Franceses.	1904	do	+100	6.3		do	D, S			125
G. Logorio	do	1904	Bored, 10 inches	128	10?		Gas	I			
Charlotte B. Clowes	do	Old.	Bored, 8 inches	(d)	9?		do	I			260
M. A. Podesto	do	1903?	Bored, 10 inches and 8 inches.	122							
Do	do	1903?	do	137	5?		Gas	I			
Do	do	1903?	Bored, 8 inches	90							
Do	do	1903?	do	165	5?		Ceased flowing	I			
S. Sanguinetti	do	1885	Bored, 8 inches?	1,162	6			N		3,500.00	
San Joaquin County	do	Old.	Bored, 6 inches	38	12.2		Wind	R			

[a] Yield estimated or statement of owner taken.
[b] Cost of well and equipment combined.
[c] Two wells.
[d] Three wells 50–76 feet deep.

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TABLE 7b.—Records of wells in San Joaquin, Contra Costa, Calaveras, and Alameda counties—Continued

San Joaquin County—Continued

Owner	Location	Year drilled	Type of construction of well	Depth of well	Depth to water level	Drop from level of water	Method of lift	Use of water	Power	Cost of well	Cost of pumping plant
				Feet	Feet	Feet					
W. A. West	Campo de los Franceses		Bored, 10 inches	140	12		Gas	I			
Do	do		do	140	12		Electric	I			
Henry Fernandez	do	1907	Bored, 8 inches	70	8		Gas	I			$1,000
Mrs. Zerega	do	[illegible]	Bored, 7 inches	1,050	0	70	Air-lift and gas	I	Small		
[illegible]	do	1906	Bored, 8 inches	117	0		Electric	I			600
[illegible] Brown	Rio Blanco	1906	Bored, 12 inches	140	10		Wind	I			
Philip Cogswell	Campo de los Franceses	1905	Bored, 8 inches	40	10		Gas	I			600
Louis Rivas	do	1907	Bored, 12 inches	80	14		do	I			
[illegible]	do	1905	Bored, 10 inches	100	11		do	I	Small		
Philip Cogswell	do	1906	do	80	8		do	I			
[illegible]	do	1904	do	80?	8		do	I			
G. Perna Partnership	do	1904	Bored, 8 inches	80	15		do	I		$75 (R)	600
G. Galliano	do	1906	Bored, 10 inches	70	10		do	I		(R)	600
S. Verconi	do	1905	Bored, 8 inches	80	10		do	I		75 (R)	975
Mr. Pescetto	do	1906	Bored, 7 inches	100	7.5		Wind	I			
Bonetti & Hualpa	do		Bored, 10 inches	100	10		Gas	I			
G. Tavernetti	do	1904	Bored, 8 inches	80	10		Wind	I			[illegible]
Julia Weber	do	1904	Bored, 7 inches	82	6.8	60	do	I, H			
W. A. Oster	Sec. 4, T. 2 N., R. 7 E.	1906?	Bored, 12 inches	70	12		Gas	I		(R)	(R)
Mrs. W. H. Beckman	Sec. 9, T. 2 N., R. 7 E.		Bored, 10 inches	78	11.8		do	I		(R)	(R)
James Brumby	do	1906	Bored, 12 inches	200	6		do	I		(R)	1,000
A. E. Mann	do	1902	Bored, 10 inches	150	15.8		do	I			850
Stephen Meier	Sec. 9, T. 2 N., R. 7 E.	1905	do	170	12		do	I		(R)	600
A. McHugh	do	1905	Bored, 12 inches	150?	8		do	I		(R)	850
Day Bros.	Campo de los Franceses	1906	Bored, 10 inches	144	14		do	I		(R)	975
D. Cotelli	do	1906	Bored, 12 inches	170?	18		do	I		150.00	700
S. Meier	do	1906	Bored, 10 inches	150	12		do	I			800
A. Pena	do		do	100?	0		do	I			600
Henry Hill	do				11.8		do	I, H			
S. A. Pearson	do	1871?	Bored, 8 inches	85	0		Wind	I, H			
S. B. Light	Sec. 11, T. 2 N., R. 7 E.	1886	Bored, 7 inches		15		do	I, H			
B. Sanguinetti	Campo de los Franceses		Bored, 10 inches	70	8		Gas	I		50.00	400
A. Sanguinetti	do	1902	do	40	12		do	I		50.00	400
N. Arata	do	1906	Bored, 8 inches	135	127		do	I		90.00	400

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San Joaquin County	....do	Old.	Bored, 4 inches	70?	9	68	Wind	R				
Foppiano Bros	Sec. 17, T. 2 N., R. 7 E.	1906	Bored, 10 inches	170	14		Gas	I		c 65	155.00	725
S. Soleri	Campo de los Franceses.	1903	Bored, 12 inches	206	18		....do	I				
Do	....do	1906	Bored, 10 inches	58	14		....do	I				
Day Bros	....do	1906	Bored, 6 inches	154	14		....do	D, S		c 9	55.00	225
L. Lagorio	....do	1903	Bored, 10 inches	80	9		....do	I				
J. Arata [a]	....do	1903	Bored, 8 inches	40	12		Wind	I			25.00	200
Do	....do	1906	Bored, 10 inches	120	12		Gas	I				400
John Beardot	....do	1904	....do	100?	12		....do	I				450
V. Cella	....do	1906	Bored, 8 inches	54	12		....do	I				285
G. Borosso	....do	1904	Bored, 10 inches	88	14		....do	I				
G. Armanino	....do	1906	....do	135	10		....do	I				285
B. Bacicoo	....do	1906	Bored, 12 inches	70	11		....do	I				400
Mrs. T. Donovan	....do	1899	Bored, 7 inches	38?	10		Wind	I				
Catherine E. Overhiser	....do	1878	Bored, 8 inches	(d)	12		Gas	I				
E. Shloezl	....do	1899	Bored, 10 inches	96	5		....do	I			45.00	250
Mrs. D. Prato	....do	1906	....do	90	12		....do	I				300
Elizabeth Loeber	....do	Old.	Bored, 8 inches	1,128	0	84	Artesian	N		c 2		
San Joaquin County	....do	Old.	Bored, 4 inches	30+	10.5		Wind	R				
Do	....do	Old.	Bored, 6 inches	40	9.2	67	....do	R				
E. S. Beecher	Sec. 25, T. 2 N., R. 7 E.	1903	Bored, 10 inches	100	9		Gas	I			40.00	450
Mr. Alling	Sec. 24, T. 2 N., R. 7 E.	Old.	Bored, 6 inches	27	13.2	69	Wind	D, S				
L. A. Gremaux	Sec. 7, T. 2 N., R. 8 E.	1901	Bored, 10 inches	110	11.5		Gas	I		c 55	75.00	490
Forest Foote	Sec. 6, T. 2 N., R. 8 E.	1902	Bored, 3 inches	60	17		Wind	D, S			15.00	60
Smith & Walch	Sec. 5, T. 2 N., R. 8 E.	1891	Bored, 4 inches	50?	18		....do	N				
R. L. Holman	Sec. 9, T. 2 N., R. 8 E.	1888	Bored, 7 inches	40	16	68	....do	D, S				50
Mrs. J. P. Ashley	Sec. 15, T. 2 N., R. 8 E.	1878?	Bored, 6 inches	28?	18		....do	D, S				
D. C. Middlekauff	....do	1904	Dug, 4 feet	30	20.3	69	Gas	I				280
P. C. Lynch	Sec. 22, T. 2 N., R. 8 E.	Old.	Bored, 7 inches	50	20		Wind	D, S			45.00	
James Sanguinetti	Sec. 27, T. 2 N., R. 8 E.	1880?	Bored, 4 inches	40	16	67	....do	D, S				
Mrs. Martha Holman	Sec. 28, T. 2 N., R. 8 E.	1866?	Bored, 6 inches	41	12		....do	D, S				
G. H. Grupe	Sec. 30, T. 2 N., R. 8 E.	1903	Bored, 11 inches	70	13		Gas	I		c 40	25.00	425
J. M. Chapin [a]	Sec. 31, T. 2 N., R. 8 E.	1905	Bored, 10 inches	90	10		....do	I		c 80		
H. J. Smyth	....do	1905	Bored, 7 inches	156	15		....do	D, I		c 6		b 330
F. Montinello	Sec. 5, T. 1 N., R. 8 E.	1905	Bored, 10 inches	150	10		....do	I		c 35		
Henry Klinger	Sec. 33, T. 2 N., R. 8 E.	Old.	Bored, 6 inches	20	6.8		Wind	D, S				
John Perado	....do	1907	Bored, 10 inches	161	10		Gas	I				
G. Cavenero	....do	1905	Bored, 12 and 6 inches.	80	9?	65	....do	I			100.00	400
Louis Carmichen	....do	1905	Bored, 12 inches	150	10		....do	I			100.00	425
Anton Canagnaro	Sec. 33, T. 1 N., R. 8 E.	1906	Bored, 8 and 6 inches.	115	10		....do	I				b 300
Peter Dondero [a]	....do	1904?	Bored, 8 inches	80	10	65	....do	I		c 20	275.00	
Sidney Newell	Sec. 3, T. 1 N., R. 8 E.	Old.	Bored, 7 inches	85?	10		Wind	S				
R. C. Gruwell	Sec. 35, T. 2 N., R. 8 E.	Old.	Bored, 3½ inches	48	17	66	....do	D, S				
O. Scheffel	....do	Old.	Dug, 4 feet	28	16		....do	D, S				
San Joaquin County	Sec. 36, T. 2 N., R. 8 E.	Old.	Bored, 7 inches	90?	24.8		....do	R				
Fifield estate	Sec. 25, T. 2 N., R. 8 E.	1866?	Dug, 3 feet	40	27		....do	N				
A. D. Fifield	Sec. 24, T. 2 N., R. 8 E.	Old.	Bored, 4 feet	56	42		....do	D, S				

[a] Two wells.
[b] Cost of well and equipment combined.
[c] Yield estimated or statement of owner taken.
[d] Four wells 130–145 feet deep.

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TABLE 39.—*Records of wells in San Joaquin, Contra Costa, Calaveras, and Alameda counties* Continued.

San Joaquin County Continued.

Owner.	Location.	Year completed.	Type and diameter of well.	Depth of well.	Depth to water level.	Temperature of water.	Method of lift.	Use of water.	Yield.	Cost of well.	Cost of machinery.
				Feet.	*Feet.*	° *F.*			*Miner's inches*		
P. C. Cassell	Sec. 32, T. 2 N., R. 9 E.	1869	Dug and bored	110	74	67	Wind	D, M			$150
Joe Potter	Sec. 19, T. 2 N., R. 9 E.	1880	Dug, 4 feet	84	28	68	do	D, M			
Mrs. Wainwright	Sec. 17, T. 2 N., R. 9 E.		Dug and bored	125	108		do	D, M			
J. F. Helms	Sec. 8, T. 2 N., R. 9 E.	1878	Dug, 4 feet	50	47		do	M			
Charles Cody	Sec. 5, T. 2 N., R. 9 E.	1880	Dug	40?	32		do	D, M			
Mrs. D. Lozier	do	Old.	do	80	70		do	D, M			
Kate D. Winship	Sec. 3, T. 2 N., R. 9 E.	Old.	Dug, 4 by 4 feet	38	27	67	do	M			
C. P. Coleman	Sec. 2, T. 2 N., R. 9 E.	Old.	do	38	24.5		do	M			
Morrell Bros	Sec. 36, T. 3 N., R. 9 E.	Old.	Dug, 3 by 3 feet	46	30	66	do	D, M			$50
C. M. Keeler	Sec. 25, T. 1 N., R. 9 E.	1898	Bored, 8 inches	92	18		do	D, M			
T. J. Brooke	Sec. 26, T. 1 N., R. 9 E.	1855	Dug and bored	180	18		do	D, M			
R. Patterson	Sec. 23, T. 1 N., R. 9 E.	1870?	Dug, 3 feet	74	30	65	do	D, M			
Do.[a]	do	1900	Dug and bored, 10 inches.	140	40		Gas	I			
Do	do	1900	do	115	40		do	I			$1,600
Mrs. Ellen Groves	Sec. 16, T. 1 N., R. 9 E.	1888	Bored, 10 inches	222	80		Wind	D, M			
M. Delmas	Sec. 4, T. 1 N., R. 9 E.	1865?	Dug, 3 feet	87	77		do	M			
Kate Winship	Sec. 9, T. 1 N., R. 9 E.	Old.	do	85?	70	70	do	M			
E. D. Alders	Sec. 17, T. 1 N., R. 9 E.	1870?	Bored, 8 inches	150	40	69	Gas	D, M, I		$100 00?	$75
A. S. Drais	Sec. 18, T. 1 N., R. 9 E.	1901	Bored	160	25		do	D, I			
W. T. Hewitt	do		Dug and bored		18	69	do				
A. W. Hewitt	Sec. 13, T. 1 N., R. 8 E.	1886	Bored, 7 inches	41	15.2		Wind	D, M			
San Joaquin County	Sec. 14, T. 1 N., R. 8 E.	1901	do	62	18		do	M			
Hewlett & Hough	Sec. 15, T. 1 N., R. 8 E.	Old	Bored, 4 inches	20	11.6		do	M			
Mrs. E. Griffin	Sec. 16, T. 1 N., R. 8 E.	1886?	do	75	12	69	do	D, M			
T. Minnahen	Sec. 4, T. 1 S., R. 8 E.	1903	do	40?	7		do	M			
J. Uriell	Sec. 33, T. 1 N., R. 8 E.		Bored	93	87	70	do	D, M			
San Joaquin County	Sec. 32, T. 1 N., R. 8 E.	Old.	Bored, 7 inches	84	5.6		do	M			
W. G. Smith	Sec. 25, T. 1 N., R. 7 E.	1870?	do	93	10		do	M			
San Joaquin County	Sec. 20, T. 1 N., R. 7 E.	Old.	do	84	4.9		do	M			
School district	Sec. 7, T. 1 N., R. 8 E.	1902	Bored, 3 inches	84	5.2	70	Hand	D			
San Joaquin County	Sec. 12, T. 1 N., R. 7 E.	Old.	Bored, 6 inches	46	4.5		Wind	M			
Dr. Young	Sec. 7, T. 1 N., R. 8 E.	1860	do	11	10		do	M			
Mrs. S. Bolliger	Sec. 1, T. 1 N., R. 7 E.	1881	Bored, 7 inches	40	10		do	D, M			
Theo. Kueppers	Campo de los Franceses.		Bored, 10 inches	180			Gas	I			
Do	do		do	150	8		do	I			$900
E. Miller estate	do		Bored, 7 inches	75	10	69	do	M, I			$75

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San Joaquin County	Sec. 11, T. 1 N., R. 7 E.	Old.	Bored, 6 inches	70	9		Wind	R			
C. F. Kuhl	Campo de los Francheses.	Old.	Bored, 7 inches	60	11		do	D, S			
Frank Peirano	do	1906	Bored, 12 inches	122	9		Gas	I	c 40	106.00	445
O. Lofquist	do	1906	Bored, 10 inches	62	7		do	I		40.00	
Fred Calosso	do	1904	Bored 8 inches	75?	12		do	I		50.00	250
James Budd	do						do	I			
R. Junker	do	1885?	Bored, 8 inches	1,010	1.5		Ceased flowing				
George Barbero	do	1906	Bored, 10 inches	130	11		Gas	I		100.00	400
Theodore Infelt	do	1905	do	64	11		do	I		48.00	375
P. Repetti	do	1904	do	95	8		do	I		50.00	285
C. L. Box	do	1894	Bored, 4 inches	120	7.5		Wind	D, S			
A. L. Selna	do	1906	Bored, 8 inches	80	12		Gas	I			
Burkett ranch	do	1871?	Bored, 4 inches	30	12		Wind	D, S			
Capetanech Bros	do	1905	Bored, 10 inches	150?	9?		Gas	I	c 30	130.00	450
Marsh estate [a]	do	1900	Bored, 7 inches	100	14		do	I	c 55		
Mrs. S. Y. Strait	do	Old.	do	1,080	0	68	Artesian	I	c 4		
James Rolero [a]	do		do	60?	10	67	do	I			
V. Lagorso	do	1905	Dug and bored	85	12		Gas	I			
Philip Cavellero	do	1906	Bored, 12 inches	175	14		do	I		135.00	490
W. Hollinbeck	do	1900	Bored, 7 inches	60	10		Wind	I			
Do	do	1900	do	100	10	69	do	I			
San Joaquin County	Sec. 27, T. 1 N., R. 7 E.	Old.	do		6		do	R			
Galgiana estate	Campo de los Francheses.	Old.	Bored, 4 inches	55	10?	70	do	S			
San Joaquin County	do	Old.	Bored, 7 inches	40?	2.8		do	R			
George Neilly	do	Old.	Bored, 4 inches	97	9		do	D, S			
W. E. Ladd	do	1880	Bored, 7 inches	975	0	73	Artesian and gas	I	Small.		
B. Sanguinnetti	do	1905	Bored, 8 inches	90	11?		Gas				
George Pock [a]	do	1903	Bored, 10 inches	100	12		do	I	c 65	200.00	700
G. B. Sanguinnetti & Co	do	1906	do	70	15		do	I			283
G. Boscacci	Stockton	Old.	Bored, 3½ inches	30	10.8	68	Hand	D			
Mr. Smith	do		Bored, 3 inches	85	10.5		Wind	D			
S. Bragetta	do	1890?	Bored, 8 inches	45	12.5		do	D, I			
Stockton Water Co	do		(d)	(d)	12		Steam	D	c 225		
Julia Gaedke	do	1890	Bored, 7 inches	100	9		Wind	D			
Stockton Gas & Electric Co	do	1893	Bored, 12 inches	1,800	0	97	Artesian	N	c 5		
State Hospital for Insane	do	1894	Bored, 15 to 8 inches	1,990	0	91	do	N			
Do	do	Old.	Bored, 8 inches ?	1,000?	10		Gas	I			
Do	do	1900?	Bored, 8 inches	80			Steam	D			
Do	do	1900?	do	150	10		do	D			
G. Scopesi	Campo de los Francheses.	1906	do	125	12		Gas	I		42.00	275
State Hospital for Insane	Stockton	1892	Bored	1,750	0	88	Artesian	N	c 10		
Stockton Gas & Electric Co	do	1895	Bored, 12 to 9 inches	1,498	0	89	do	N	c 15		
Citizens Gas Co	do	1890	Bored, 12 inches ?	2,078	0	96	do	N	c 125		
Stockton Water Co. [a]	do	1903–4	Bored, 12 inches	800	10		Electric	D	c 185		

[a] Two wells.
[b] Cost of well and equipment combined.
[c] Yield estimated or statement of owner taken.
[d] Eleven wells, 8–20 inches in diameter and 200–1,100 feet deep.

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TABLE 39.—*Records of wells in San Joaquin, Contra Costa, Calaveras, and Alameda counties*—Continued.

San Joaquin County—Continued.

Owner.	Location.	Year completed.	Type and diameter of well.	Depth of well.	Depth to water level.	Temperature of water.	Method of lift.	Use of water.	Yield.	Cost of well.	Cost of machinery.
				Feet.	*Feet.*	° *F.*			*Miner's inches.*		
Central Natural Gas Co	Stockton			1,400	0		Artesian	N			
Citizens Gas Co	do	1904	Bored	1,786	0	94	do	N	a 125		
Crown Mills	do	1890	do	1,210	0	90	do	N	a 10		
Stockton Gas & Electric Co	do	1899	Bored, 12 inches	2,500	0	101	do	N			
California Paper Co	do		Bored, 12 to 6 inches.	1,228	0		do	N		$2,500.00	
Stockton Gas & Electric Co	do	1888	Bored	2,254			Ceased flowing	N			
Do	do	1890	do	1,400	0		Artesian	N	Small.		
Do	do	1892?	Bored, 12 to 7 inches.	1,800	0		do	N			
Citizens Gas Co	do	1890	Bored, 12 to 6 inches.	2,078	0		do	N			
Do	do	1903	do	1,600?	0		do	N			
San Joaquin County	do	1890	Bored, 12 to 8 inches.	2,000	8		Ceased flowing	N		5,884.00	
San Joaquin County and Stockton	do	1857	Bored, 9 to 8 inches.	1,003	0	77	Artesian	N		10,000.00	
St. Agnew's College	do	1889	Bored		0		do				
Do	do	1892	Bored, 10 to 6 inches.	1,720	0		do		a 10		
George Dawson	do	1898	Bored, 4 inches	110	3?		Wind	D			
Dr. Clark	do		Bored, 10 inches	90	5?		Gas	I			
Suren Jackson	do	1893–4	Bored, 12 to 9 inches.	1,700	0	85	Artesian	Baths.	a 50		
Do	do	1893–4	do	1,850	0	85	do	Baths.			
Pacific Window Glass Co	do		Bored, 12 inches	2,100?	0	88	do		a 15		
W. S. Moss estate	Campo de los Franceses.	Old.	Bored, 4 inches	40	5.5		Wind	D, S			
H. P. Fitch	do	1901?	Bored, 9½ inches	200?	4		Gas	I		100.00?	$375
Mr. Zinango	do	1885?	Bored, 7 inches	60							
Do	do		do	35	15	66	Wind	I			
Mrs. C. Fraser	do	Old.	Bored, 6 inches	60	10		do	D, S			40
A. C. Ashley	do	Old.	Bored, 4 inches	70	20		do	D, S			
A. Baker	do	Old.	Bored, 8 inches	80	25		do	S, I			125
Michael Earney	Sec. 28, T. 1 N., R. 7 E.	1892	Bored, 4 inches	80	8		do	D, S			
Mrs. Keller	Sec. 27, T. 1 N., R. 7 E.	1882	do	100	20		do	D			
Dr. Asa Clark	Campo de los Franceses.		Bored, 18 to 15 inches.	106	4.5		Gas	I			
Sperry Flour Co	do	Old.	Bored, 4 inches		10	67	Wind	D, S			

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C. B. McDougald	Sec. 26, T. 1 N., R. 6 E.	Old.	Bored				Ceased flowing	N			
San Joaquin County	Sec. 16, T. 1 N., R. 6 E.	Old.	Bored, 7 inches	23	3		Wind	R			
J. J. Sober	do	1898	Bored, 4 inches	100	4.5		do	D,S			
Do	Sec. 19, T. 1 N., R. 6 E.		Bored, 6 inches	23	6.7	62	do	S			
School district	Sec. 7, T. 1 N., R. 6 E.	Old.	Bored, 3½ inches	33	4.3		Hand	D			
Charles D. Puerst Land & Sales Co	Sec. 6, T. 1 N., R. 6 E.	1907	Bored, 7 inches	90	2.5		Wind	D			
Wood Bros	Sec. 24, T. 1 N., R. 5 E.		Bored, 4 inches	40	5?		do	D,S			
W. J. Thompson	Sec. 23, T. 1 N., R. 5 E.		do	38	11	65	do	D,I			
San Joaquin County	Sec. 20, T. 1 N., R. 6 E.	Old.	Bored, 7 inches	85	4.5		Not raised	N			
A. Grunaur	Sec. 29, T. 1 N., R. 6 E.	Old.	Bored, 3 inches		10.5	64	Wind	D,S			
J. J. Cassiday	Sec. 32, T. 1 N., R. 6 E.		do	32	11		do	D,S			
L. J. Squires	Campo de los Franceses.	1903?	Bored, 8 inches	110	11		Gas	I		100.00?	400
S. A. Gaffney	do	1903	Bored, 12 inches	182	13		do	I	a 50		c 500
J. P. Wilson	do	1904	Bored, 8 inches	110	14		Gas	I			
Joseph Yettner b	do	1904	Bored, 8 inches?	200	8		do	I			c 1,500
Lorenzo Hurd	do	1905	Bored, 12 inches	213	14		do	I		300.00	335
William Brown	Sec. 6, T. 1 S., R. 6 E.	1890	Bored, 7 inches	30	11	66	Hand	D,S			
J. Woods	Sec. 1, T. 1 S., R. 5 E.	Old.	Bored, 2½ inches	52	5.5	65	do	D,S			
J. Williams	Sec. 2, T. 1 S., R. 5 E.	Old.	Bored, 7 inches		10.5		Wind	D,S			
Frank H. Johnson	Sec. 22, T. 1 S., R. 5 E.	1884	Bored, 10 inches	1,400	0	84	Artesian	N			
Do	do		Bored, 7 inches	30	8	65	Wind	D,S			
Henry Meyers	Sec. 19, T. 1 S., R. 6 E.	1898?	Bored, 3 inches	80	8	66	do	D,S			
J. F. Kranz	Sec. 20, T. 1 S., R. 6 E.	1897	Bored, 4 inches	43	9		do	D,S			
Do	Sec. 17, T. 1 S., R. 6 E.	1897	Bored, 3 inches	40	9		do	D,S			
G. F. Slankard	Campo de los Franceses.	1904	Bored, 8 inches	130	8		Gas	D,S			600
Nicola Grecco	do	1906	Bored, 6 inches	108	9		Gas	I	a 20	54.00	280
W. J. Rhoades	do	1905	Bored, 11 inches	123	9	67	do	I,S		123.00	450
Do	do	1905	Bored, 16 inches	107	9		do	I,S	a 211	300.00	2,150
J. A. McAfee	do	1898	Bored, 2½ inches	200	11		Wind	D,S			
Burdett Salmon	do	Old.	Bored	1,200	0		Artesian	N	a 5		
Mrs. Nellie Comstock	Sec. 8, T. 1 S., R. 7 E.	1881?	Bored, 7 inches	1,250	0	77	do	N			
H. A. Hoerl	Sec. 13, T. 1 S., R. 6 E.	1906	Bored, 12 inches	90	10		Gas	I	100	128.00	700
Mrs. Anna Ross	Sec. 24, T. 1 S., R. 6 E.	1906	do	125	7		do	I	133	150.00	900
T. M. Brockman	Sec. 25, T. 1 S., R. 6 E.	1906	do	115	9		do	I	100	20.00	650
P. Alex	Sec. 26, T. 1 S., R. 6 E.	1903	Bored, 10 inches	44	9	59	do	I	25	80.00	450
W. Litchfield	do	1906	Bored, 12 inches	131	10	58	Gas	I	100	200.00	
L. W. Holland	do	1905	Bored, 10 inches	50	16	62	do	I	45		675
	Sec. 25, T. 1 S., R. 6 E.	1890	Bored, 8 inches	1,200	0	74	Artesian	N	8		
Mrs. Garrison	Sec. 36, T. 1 S., R. 6 E.	Old.	Bored, 7 inches	48	10?	58	Wind	D,S			
G. H. Shedd	do	1896	Bored, 2 inches	80	8		do	D,S		15.00	60
A. E. Munter	Sec. 1, T. 2 S., R. 6 E.	1891	Bored, 4 inches	100	18		do	D,S			
E. R. Olds	Sec. 32, T. 1 S., R. 7 E.	1905	do	70	12		do	D,S			80
D. R. Reynolds	Sec. 30, T. 1 S., R. 7 E.	1871	do	35	7	65	do	D,S			40
Mrs. E. F. Salmon	Sec. 29, T. 1 S., R. 7 E.	Old.	Bored, 5 inches	75	15		do	D,S			
E. Reynolds	Sec. 30, T. 1 S., R. 7 E.	1905	Bored, 16 inches	115	14	64	Gas	I	a 177	250.00	1,000
D. O. Castle	Sec. 16, T. 1 S., R. 7 E.	1898	Bored, 3 inches	40	5		Wind	D,S			
M. Henry	Sec. 15, T. 1 S., R. 7 E.	1899	Bored, 6 inches	130	5.8		do	D,S			
Josephine Hitchcock	Sec. 23, T. 1 S., R. 7 E.	1885?	do	28	3.5	66	do	D,S			
C. A. Miller	Sec. 24, T. 1 S., R. 7 E.	1883	Bored, 4 inches	45	3.5		do	D,S			

a Yield estimated or statement of owner taken. b Two wells. c Cost of well and equipment combined.

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TABLE 39. *Records of wells in San Joaquin, Contra Costa, Calaveras, and Alameda counties*—Continued

San Joaquin County—Continued

Owner	Location	Year com-pleted	Type and diameter of well	Depth of well	Depth to water level	Head above (+) or below (−) land surface	Method of lift	Use of water	Yield	Cost of well	Cost of lift and other data
				Feet	Feet	Feet			Miner's inches		
M. S. Foster	Sec. 30, T. 1 S., R. 8 E.	1901	Bored, 4 inches	140	4		Wind	D. M.			
Albert Doe	Sec. 20, T. 1 S., R. 8 E.	1907	do	1907	11		do	D. M.			
J. Dembichelis & Co.	Sec. 21, T. 1 S., R. 8 E.	1901	Bored, 10 inches	40	8	+4	Gas				$800
G. H. Hall	Sec. 16, T. 1 S., R. 8 E.	1900	Bored, 7 inches	80	5.0		Wind				
G. W. Mourey	Sec. 3, T. 1 S., R. 8 E.		Dug	18	10		do				
B. F. Hardin	Sec. 15, T. 1 S., R. 8 E.	1907	Bored, 4 inches	97	4.7		do				
Minges estate	Sec. 23, T. 1 S., R. 8 E.	1907	Bored, 4 inches	107	10		do				
Louis Cook	Sec. 28, T. 1 S., R. 8 E.	1907	Bored	90	8		do				
Doe estate	Sec. 12, T. 1 S., R. 8 E.	1907	Bored, 4 inches	90	8	+6	do				
James Turner	do	1907	Bored, 4 inches	20	8		Unused				
G. E. Minges	Sec. 33, T. 1 S., R. 8 E.	1906	Bored, 10 inches	21	10.8		Wind	D. M.			
E. Wagner	Sec. 4, T. 2 S., R. 8 E.	1906	Bored, 4 inches	14	11.1	+7	do	D. M.			
G. H. Daley	Sec. 1, T. 2 S., R. 8 E.	1907	do	107	30		do	D. M.			
School district	Sec. 5, T. 2 S., R. 8 E.		Bored, 7 inches	401	22.5		do	D. M.			
Fred Holmsten	Sec. 31, T. 1 S., R. 8 E.	1907	Bored	48	25		do	D. M.			
Charles Rutherland	Sec. 19, T. 1 S., R. 8 E.	1907	do	80	8		do	D. M.			
Hiram Jones estate	Sec. 20, T. 1 S., R. 8 E.	1900	Bored, 7 inches	100	17.5		do	D. M.			
J. H. Strother	Sec. 9, T. 1 S., R. 8 E.	1907	do	96	40		do	D. M.			
H. C. Fisher	Sec. 5, T. 1 S., R. 8 E.	1907	do	94	91.5		Not installed				
Santa Fe Ry. Co.	Sec. 4, T. 2 S., R. 8 E.	1906?	do	1907	15	+50	Steam	D.	4.00		
William Campbell	Sec. 3, T. 2 S., R. 8 E.	1905?	do	80	41		Wind	D. M.			
Jones estate	Sec. 1, T. 2 S., R. 8 E.	1906?	Bored, 7 inches	94	0.0		do	D. M.			
Mrs. D. Sutliff	Sec. 12, T. 2 S., R. 8 E.	1901	do	102	80	+8	do	D. M.			
D. L. Jones	Sec. 16, T. 2 S., R. 8 E.	1901	do	100	81		do	D. M.			$800
Myers Bros.	Sec. 17, T. 2 S., R. 8 E.	1907	Dug, 3 feet	30	22.5		do	D. M.			
John Hall	Sec. 19, T. 2 S., R. 8 E.	1907	Bored, 7 inches	70	56	+8	do	D. M.			
Mrs. Tottrall	Sec. 24, T. 2 S., R. 8 E.	1871	do	40	30?		do	D. M.			50
Mrs. Eichoff	Sec. 14, T. 2 S., R. 8 E.	1907	do	75	64.0		do	D. M.			
J. S. Moulton	Sec. 20, T. 2 S., R. 8 E.	1907	Bored, 14 inches	128	92		Gas			$600 (?)	$600
G. B. Matthews	do	1906	Bored, 7 inches	42	11		Wind	D. M.		91.00	40
Dan O'Leary[a]	Sec. 17, T. 2 S., R. 8 E.	1905	Bored, 10 inches	130	14		Gas				$600
J. B. Thorpe	Sec. 7, T. 2 S., R. 8 E.	1901	Bored, 7 inches	65	20		do				$600
G. W. Samson	Sec. 35, T. 2 S., R. 7 E.	1907	Bored	20	16	61	Wind	D. M.			
Mrs. Frank Hutchinson	do	1907	Bored, 7 inches	85	13		do	D. M.		52.00	60
Joe Willard	Sec. 27, T. 2 S., R. 7 E.	1905	Bored	80			do	D. M.			
W. J. Buchanan	Sec. 15, T. 2 S., R. 7 E.	1905	Bored, 6 inches	40	11		do	D. M.		26.00	60
John Swett	do		Bored				Gas				
William Moser	Sec. 14, T. 2 S., R. 7 E.	1904	do	85	14		Wind	D. M.			

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Hals Bros.	Sec. 11, T. 2 S., R. 7 E.	1905	Bored, 4 inches.	34	9		Hand	D		16.00		
Mrs. B. McMullin	Sec. 20, T. 2 S., R. 7 E.	Old.	Bored	45	30?	62	Wind	S				
J. W. Thompson estate	Sec. 13, T. 2 S., R. 6 E.	1899	Bored, 10 inches	131	16	59	Gas	I	95			
West & Wilhoyt	Sec. 8, T. 2 S., R. 7 E.	1900	Bored, 4 inches	100	10		Wind	D, S				
W. J. Woodward	Sec. 7, T. 2 S., R. 7 E.	1905	Bored, 12 inches	102	13	66	Gas	I	[b] 110	170.00	2,000	
H. B. Bright	Sec. 2, T. 2 S., R. 6 E.	1898	Bored, 10 inches	125	6	62	do	I		125.00	860	
Mr. Varney	Sec. 12, T. 2 S., R. 6 E.		Bored, 4 inches	36	16	62	Wind	D, S				
G. W. Wetherby	Sec. 11, T. 2 S., R. 6 E.	1904	Bored	80	8	62	do	D, S				
W. M. Robinson	Sec. 24, T. 2 S., R. 5 E.	1899	Dug, 3 feet	20	12.7		Wind and gas	D, I				
McLaughlin & Co	El Pescadero (Grimes)		Bored	29	5		Wind	D, S				
Do	do	1890	Dug, 3 feet	12	9	72	do	D, S				
Mrs. M. R. Robbins	do	1899	Bored, 6 inches	80	4.5		do	D, S				
Mountian Bros	Sec. 32, T. 2 S., R. 4 E.	1888	Dug, 4 feet	37	32		do	D, S			60	
Mrs. E. Hewson	Sec. 4, T. 2 S., R. 4 E.	1886?	Dug, 3 feet	50	45		do	D, S			120	
William Liendemann	Sec. 8, T. 2 S., R. 4 E.	1880	Bored	100	90		do	D, S			26	
McLaughlin & Co	Sec. 9, T. 2 S., R. 4 E.	Old.	Bored, 8 inches	65	40		do	D, S				
Fabian & Co	Sec. 10, T. 2 S., R. 4 E.	Old.	Bored, 7 inches	95	38		do	D, S				
P. Hansen	do	1866?	Dug, 3 feet	40	33.6		do	S				
D. J. Tooney	Sec. 11, T. 2 S., R. 4 E.	1899	Bored, 6 inches	75	30		do	D, S		107.00		
Mrs. Emily Odell	Sec. 17, T. 2 S., R. 4 E.	Old.	Bored, 7 inches	125	85		do	D, S				
George Luhrsen	Sec. 14, T. 2 S., R. 4 E.		Bored, 8 inches	167	45		do	D, S				
Pacific Coast Oil Co	Sec. 13, T. 2 S., R. 4 E.	1904	do	468	12		Steam	D, B				
Mrs. Coogan	Sec. 22, T. 2 S., R. 4 E.	1871?	Bored, 7 inches	200			Wind	D				
T. H. Henderson	do	1888	do	160	94		do	D, S				
J. E. Faulkner	Sec. 21, T. 2 S., R. 4 E.	1900	do	200	112		do	D, S			210	
H. Boltzen	Sec. 28, T. 2 S., R. 4 E.	1885	Bored	455	80		do	D, S				
Hall Cordez	Sec. 27, T. 2 S., R. 4 E.	Old.	Bored, 7 inches	300	180		do	D, S				
J. A. Cordes	Sec. 34, T. 2 S., R. 4 E.		Bored, 6 inches	+93	93+		do	D, S				
Fabian & Co	Sec. 33, T. 2 S., R. 4 E.	1897?	Bored, 7 inches	200	.7	72	Hand	D, S		350.00		
Mrs. S. Slickman	Sec. 34, T. 2 S., R. 4 E.		Dug, 3 feet	30	27	63	do	D, S				
A. Frahmann	Sec. 35, T. 2 S., R. 4 E.	1868	Bored, 8 inches	200	160		Wind	D, S			[c] 225	
Fabian & Co	Sec. 25, T. 2 S., R. 4 E.		Dug, 3 feet	97	88.8		do	N				
Do	Sec. 30, T. 2 S., R. 5 E.	1889?	Bored, 8 inches	50	28		do	D, S			35	
Peter Holm	Sec. 24, T. 2 S., R. 4 E.		Dug, 3 feet	38	34.5	67	do	D, S				
F. Von Sosten	do	1897	Bored, 8 inches	247	30		do	D, S		300.00	75	
John G. Deane	Sec. 20, T. 2 S., R. 5 E.	1895?		72	15	69	do	D, S		50.00	27	
William Golden	do		Dug, 3 feet	27	24.5		do	D, S				
J. S. Krohn	Sec. 30, T. 2 S., R. 5 E.	1885	Bored	100	28		do	D, S				
Southern Pacific Co	Sec. 28, T. 2 S., R. 5 E.	1898	Bored, 10 inches	157	30		Gas	B	[b] 13			
A. Grunauer	Sec. 22, T. 2 S., R. 5 E.	1906	Bored, 8 inches	698	29	67				2,600.00		
John Chrisman	do	1867	Dug and bored, 7 inches.	45	31		Wind	D, S		80.00		
C. M. Batterman	Sec. 24, T. 2 S., R. 5 E.	1898	Dug	+37	30.5	69	Hand	D, S				
Jacob Rhodes	Sec. 30, T. 2 S., R. 6 E.	1869	Bored	52	30		Wind	D, S		62.00	140	
J. Rathaen	Sec. 36, T. 2 S., R. 5 E.	1867	Bored, 6 inches	110	40		do	D, S			160	
H. R. Ludwig	Sec. 2, T. 3 S., R. 5 E.	Old.	Bored, 7 inches	175	80		do	D, S				
A. Buschke	Sec. 33, T. 2 S., R. 5 E.	1888	Bored	140	100		do	D, S				
Tracy cemetery	Sec. 28, T. 2 S., R. 5 E.		Bored, 7 inches	76	57		do	I				
John Frerichs	Sec. 32, T. 2 S., R. 5 E.	1886?	do	130	80		do	D, S				
William Carroll	Sec. 4, T. 2 S., R. 5 E.	1888	Bored	90	40		do	D, S				
Fabian & Grunaur	Sec. 7, T. 3 S., R. 5 E.		Bored, 8 inches?	130			do	D, S				

[a] Two wells.

[b] Yield estimated or statement of owner taken.

[c] Cost of well and equipment combined.

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TABLE 39. *Records of wells in San Joaquin, Contra Costa, Calaveras, and Alameda counties.* Continued.

San Joaquin County. Continued.

Owner.	Location.	Year completed.	Type and diameter of well.	Depth of well.	Depth to water level.	Temperature of water.	Method of lift.	Use of water.	Yield.	Cost of well.	Cost of machinery.
				Feet.	Feet.	° F.			Miner's inches.		
John Collins	Sec. [illegible], T. [illegible] S., R. [illegible] E.	[illegible]	Bored, 7 inches	[illegible]	[illegible]		Wind	D, S			
School district	Sec. [illegible], T. [illegible] S., R. [illegible] E.	[illegible]	do	[illegible]	[illegible]		do	D, S			
Mrs. S. M. Schlossman	Sec. [illegible], T. [illegible] S., R. [illegible] E.	[illegible]	Bored, [illegible] inches	[illegible]	[illegible]		do	D, S			$[illegible]
J. Brichgetto	do	Old	Bored, 7 inches	[illegible]	[illegible]		do	D, S			
Ed. Mitchell	Sec. [illegible], T. [illegible] S., R. [illegible] E.	Old	do	[illegible]	[illegible]		do	D, S			
John Rogers	Sec. [illegible], T. [illegible] S., R. [illegible] E.		Bored, [illegible] inches	[illegible]	[illegible]		do	D, S			
J. W. Peterman	do	[illegible]	Bored, [illegible] inches	[illegible]	[illegible]		do	D, S		$100.00	
Bert Elm	Sec. [illegible], T. [illegible] S., R. [illegible] E.		Bored, 7 inches	[illegible]	[illegible]		do	D, S			
	Sec. [illegible], T. [illegible] S., R. [illegible] E.		do	[illegible]	[illegible]		do	D, S			
Mrs. M. Schroeder	Sec. [illegible], T. [illegible] S., R. [illegible] E.	Old	do	[illegible]	[illegible]		do	D, S			
D. Gerlach	Sec. [illegible], T. [illegible] S., R. [illegible] E.	[illegible]	do	[illegible]	[illegible]		do	D, S		[illegible]	[illegible]
C. Brandeman	Sec. [illegible], T. [illegible] S., R. [illegible] E.	[illegible]	do	[illegible]	[illegible]		do	D, S			
Benjamin Worcester	Sec. [illegible], T. [illegible] S., R. [illegible] E.		do	[illegible]	[illegible]		do	D, S			
N. Conelly	Sec. [illegible], T. [illegible] S., R. [illegible] E.		Bored, [illegible] inches	[illegible]	[illegible]		do	D, S		[illegible]	[illegible]
J. Brichgetto	Sec. [illegible], T. [illegible] S., R. [illegible] E.	[illegible]	Bored, [illegible] inches	[illegible]	[illegible]		do	D, S			
E. Kern	Sec. [illegible], T. [illegible] S., R. [illegible] E.	[illegible]	Bored, 7 inches	[illegible]	[illegible]		do	D, S			
J. Brichgetto	Sec. [illegible], T. [illegible] S., R. [illegible] E.	[illegible]	do	[illegible]	[illegible]		do	D, S			
Jacob Ohm	El Pescadero (Grimes)	[illegible]	Bored, [illegible] inches	[illegible]	[illegible]		do	D, S			
T. Nicholson	Sec. [illegible], T. [illegible] S., R. [illegible] E.		Bored, [illegible] inches	[illegible]	[illegible]		do	D, S			[illegible]
School district	Sec. [illegible], T. [illegible] S., R. [illegible] E.		Bored, [illegible] inches	[illegible]	[illegible]		do	D, S			
Stockton Savings & Loan Association	Sec. [illegible], T. [illegible] S., R. [illegible] E.	Old	Bored, 7 inches	[illegible]	[illegible]		do	D, S			
Stockton Savings Bank	El Pescadero (Grimes)		do	[illegible]	[illegible]		do	D, S			
L. Gerlach	do	[illegible]	Bored	[illegible]	[illegible]		do	D, S			
Do	do		Bored, [illegible] inches	[illegible]	[illegible]		do	D, S			
John Ohm	do	[illegible]	Bored, 7 inches	[illegible]	[illegible]		do	D, S		[illegible]	[illegible]
Jacob Ohm	Sec. [illegible], T. [illegible] S., R. [illegible] E.	[illegible]	do	[illegible]	[illegible]		do	D, S		[illegible]	[illegible]
Richard Brown	Sec. [illegible], T. [illegible] S., R. [illegible] E.	[illegible]	Bored, [illegible] inches	[illegible]	[illegible]		do	D, S		[illegible]	[illegible]
George Thoming	Sec. [illegible], T. [illegible] S., R. [illegible] E.	[illegible]	Bored	[illegible]	[illegible]		do	D, S			
N. Kister	do	[illegible]	Bored, 7 inches	[illegible]	[illegible]		do	D, S		[illegible]	[illegible]
J. Brichgetto	Sec. [illegible], T. [illegible] S., R. [illegible] E.	[illegible]	Bored	[illegible]	[illegible]		do	D, S			
D. K. Fake	Sec. [illegible], T. [illegible] S., R. [illegible] E.	[illegible]	Bored, [illegible] inches	[illegible]	[illegible]		do	D, S			

Contra Costa County.

Mr. Hooper	Los Medanos	1892	Bored	30	22.5		Wind	D, S			
Do	do	Old	Bored, 6 inches	30	55		do	D, S			

Pacific Coast Oil Co.	do	1904	Bored, 8 inches	166	70		Steam	D, S			
C. A. Hooper	do	1881?	Bored, 6 inches	65	15		Wind	D, S			
Mr. Williamson	do	1891	Dug	100	90		do	D, S			
Do	do		Bored, 7 inches		22.7		do	D, S			
Thomas Wallace	do	1892?	Bored	60	40		do	D			
J. H. Trythall	Sec. 19, T. 2 N., R. 2 E.	1896	do	35	29		do	D			50
Mrs. M. E. Evans	Sec. 20, T. 2 N., R. 2 E.	1902	do	65	30		do	D, S		80.00	
	Sec. 21, T. 2 N., R. 2 E.		Bored, 8 inches	61	33.2		do	D			
S. T. Heimbach	Sec. 22, T. 2 N., R. 2 E.	1902	Bored	82	60	62	do	D			70
J. Rodrigues	do	1894	Bored, 6 inches	65	45		do	D			
Mrs. Schults	Sec. 26, T. 2 N., R. 2 E.	1891	Bored, 7 inches		55		do	D			
R. P. Banenti	Sec. 25, T. 2 N., R. 2 E.	1904	do	70	22.6		do	D		52.00	
B. F. Porter estate	do	1896	Bored	65	10		do	D, S			
F. Enas	Sec. 30, T. 2 N., R. 3 E.	Old.	Bored, 6 inches	28	24		do	D, S			
Mrs. F. M. Morton	Sec. 31, T. 2 N., R. 3 E.		Bored, 10 inches	72	14		Gas	I			
George Sellers	do	1902	Bored, 8 inches	36	13		do	I	a 40	36.00	390
O. C. Austen	do	1902	do	31	11		do	I	20		b 392
Mrs. L. Barnum	Sec. 36, T. 2 N., R. 2 E.	1891	Driven, 7 inches	54	36		do	D			70
A. Whitaker	Sec. 35, T. 2 N., R. 2 E.	1906	Dug, 4 feet	65	62.5		Hand	D			
McLaughlin Co	Sec. 1, T. 1 N., R. 2 E.		Bored	75			Wind	D, S			
Robert Cakebread	Sec. 2, T. 1 N., R. 2 E.		do	600	60		do	S			
Frank McFarland	Sec. 3, T. 1 N., R. 2 E.	1890	Dug, 4 feet	75	5.5		do	D, S			
W. C. Williamson	Sec. 4, T. 1 N., R. 2 E.	1881?	Dug	36	16		do	S			45
	Los Medanos		Dug, 3 feet		40.5		do	D, S			
Los Medanos	do	1902	Bored, 6 inches	72	40	66	do	D, S			
Marsh Grant	do	Old.	do	61	32.5		do	D, S			
Gedes & Rindigen	do	1886?	Bored, 8 inches	140	40		do	D, S			
R. E. Le Moin	Sec. 7, T. 1 N., R. 3 E.	Old.	Bored, 6 inches	100	50		do	D, S		100.00	
J. R. Bayer	Sec. 8, T. 1 N., R. 3 E.	1900	do	50			do	D			
W. F. Pierce	Sec. 4, T. 1 N., R. 3 E.	1891	Bored, 7 inches	60	15		do	D		50.00	50
George Alfritz & Co	Sec. 3, T. 1 N., R. 3 E.	Old.	Dug, 3 feet	35	15		do	D, S			45
W. J. Estes	Sec. 10, T. 1 N., R. 3 E.	1866	Bored, 6 inches	30	16		do	D, S			
D. Rhodes	Sec. 14, T. 1 N., R. 3 E.	1876	Dug, 3 feet	14	10	68	Hand	D, S			
E. D. Griggsby	Sec. 16, T. 1 N., R. 3 E.	1876?	Bored	90	18		Wind	D, S			
Do	Sec. 17, T. 1 N., R. 3 E.	1886?	Bored, 6 inches	75	35		do	D, S			80
P. G. King	Sec. 20, T. 1 N., R. 3 E.	Old.	do		26		do	D, S			
Marsh Grant	Los Medanos	Old.	do	50			do	D, S			
Mellow & Doulart	do	Old.	Dug	27	23	64	Hand	D			
John Boyd	do	1898	do	77	73		do	D, S		14.00	40
Pacific Coast Oil Co	Sec. 29, T. 1 N., R. 3 E.	1904	Bored, 8 inches	367	4?		Steam	D, B			
A. Allen	Sec. 28, T. 1 N., R. 3 E.	1904	Bored, 5 inches	48	29		Wind	D, S		22.00	
P. Buedewick	Sec. 27, T. 1 N., R. 3 E.	1891	Bored, 8 inches	60	30		do	D, S			
M. A. Michaelson	do	1887	Bored, 6 inches	52	12		do	S, I			
J. Q. Wrenn	Sec. 26, T. 1 N., R. 3 E.	Old.	Bored, 10 inches	300	7		do	S, I			
C. W. Lent	Sec. 23, T. 1 N., R. 3 E.		Bored, 6 inches	195	10		Not raised	N			
W. J. Livingston	Sec. 34, T. 1 N., R. 3 E.	Old.	Bored	+100	15		Wind	D, S			
J. S. Netherton	Sec. 28, T. 1 N., R. 3 E.	1876?	Bored, 3 inches	32	16	64	Hand	D			
V. Taylor	Sec. 33, T. 1 N., R. 3 E.	1874	Bored, 5 inches	40	23		Wind	D		40.00	100
A. M. Plumley	Sec. 34, T. 1 N., R. 3 E.	1899?			8		do	D			
W. M. Chilson	Sec. 3, T. 1 S., R. 3 E.	1904	Bored, 7 inches	48	14	61	Gas	I			130
W. A. Farthingham	Sec. 2, T. 1 S., R. 3 E.	Old.	Bored, 6 inches		6		Wind	D, S			

a Yield estimated or statement of owner taken.

b Cost of well and equipment combined.

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TABLE 39.—*Records of wells in San Joaquin, Contra Costa, Calaveras, and Alameda counties*—Continued.

Contra Costa County—Continued.

Owner.	Location.	Year completed.	Type and diameter of well.	Depth of well.	Depth to water level.	Temperature of water.	Method of lift.	Use of water.	Yield.	Cost of well.	Cost of machinery.
				Feet.	*Feet.*	° *F.*			*Miner's inches.*		
N. Peterman	Sec. 11, T. 1 S., R. 3 E.	1905	Bored, 12 inches	45	7	61	Gas	I.	a 110	$90.00	$600
W. W. Stone	Sec. 10, T. 1 S., R. 3 E.	1895	Bored, 6 inches	21	13	62	Wind	D,S.		12.00	104
B. Nelson	do	1886?	Bored	60			do	D,S.			
Mrs. M. Schmidt	Sec. 4, T. 1 S., R. 3 E.	1871?	Bored, 7 inches	46	17		do	D,S.			
E. M. Anderson	Sec. 22, T. 1 S., R. 3 E.		Dug, 4 feet		14.5	62	do	D,S.			
Mrs. M. Klesow	do		Dug, 3 feet	45	37	70	Hand	D			
H. Bruns	Sec. 26, T. 1 S., R. 3 E.		Dug	30			Wind	D			
C. F. Wright	do	1889	Dug, 3 feet	42	30	69	do	D,S.			130
Fabian & Co	Sec. 30, T. 1 S., R. 4 E.		do		30		Hand	D			
Calaveras County.											
R. L. Peterson	Sec. 14, T. 2 N., R. 10 E.	1890	Bored, 6 inches	315	160		Wind	D			
Rhodes & Co	Sec. 10, T. 2 N., R. 10 E.	1901	Bored, 13 inches	850?	160		Not raised	N			
E. F. Gall	Sec. 9, T. 2 N., R. 10 E.	1890	Dug, 4 feet	110	99		Wind	D,S.			$100
Alameda County.											
James Faulkner	Sec. 20, T. 2 S., R. 4 E.		Bored, 4 inches	200	0	69	Artesian	S	Small.		
H. C. Peterson	Sec. 6, T. 2 S., R. 4 E.	1902	Dug, 4 feet	74	62		Wind	S			$40
A. D. Gordon	Sec. 36, T. 1 S., R. 4 E.	Old.	Dug				do	S			

a Yield estimated or statement of owner taken.

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STANISLAUS COUNTY.

GENERAL CONDITIONS.

Stanislaus County, like Merced, extends entirely across San Joaquin Valley, and therefore both east-side and west-side conditions are represented within it. The valley in this latitude is contracted somewhat, so that its width is greater both to the north and to the south than here.

South of Tuolumne River and east of the San Joaquin, the canals of the Turlock irrigation district supply gravity water to a large part of the valley; and north of the Tuolumne the canals of the Modesto district supply the west-central part of the county from a point about 8 miles east of Modesto to San Joaquin River. West of the San Joaquin the lower line of the San Joaquin and Kings River canal system extends to the vicinity of Crows Landing. Under these canal systems much alfalfa is raised, dairying is an important and growing industry, and there is an increasing acreage devoted to fruit raising and diversified farming. Outside of the irrigated district the greater part of the valley lands are in grain, both wheat and barley being raised, although here, as in other parts of the Great Valley, the production is less than formerly. Along the San Joaquin the flooded bottoms and the neighboring alkali lands are used for grazing.

Less use is made of ground waters in this county than in any other part of the valley. The rainfall is sufficient, so that grain raising has been successful in the past, and irrigation has not been absolutely necessary in order that the valley lands might be utilized. The pressure for irrigation therefore has not been so intense as in the more strictly arid sections farther south. Furthermore, the surface supply is more nearly adequate than in many of the counties, and the limits of productivity through the use of the cheap gravity waters have not been reached, because the Turlock and Modesto districts are not yet fully developed. Because of this large supply of surface water and its as yet incomplete utilization little interest has been taken heretofore in the development and use of ground waters.

FLOWING WELLS.

The Survey has records of only five flowing wells in the county. These are near the southern boundary, and most of them are west of San Joaquin River. Only one, that on the McDermott estate, northeast of Newman, is used for irrigation. The others furnish supplies for stock.

Because of the meager development, the limits of the area within which flowing waters are to be expected has not been determined with certainty. Nor are these limits of as much importance here as

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farther south in the valley, because the flowing wells will yield rather meagerly, their waters will be of poor quality generally, and the flowing-well area will be confined to a zone of low land along the axis of the valley, much of which is subject to overflow and some of which is alkaline.

The settlers along the west side—owners of fertile, alkali-free soils, capable of immense production if water could be applied to them, but practically limited under present conditions to dry crops—are as a matter of course deeply interested in the possibility of securing irrigation water from any source. The streams that flow from the west-side hills toward the valley are wet-weather streams of slight flow and can not be considered as sources of irrigation water.

The San Joaquin and Kings River canal system may be capable of slight extension when irrigation practice on the lands under it improves; but at best it can serve only a small additional acreage. It is probable that pumping systems will eventually be installed to lift water directly from the San Joaquin to apply to those west-side lands that are within 40 or 50 feet of the low-water level in the river. Pumping plants may also be installed in the lower west-side lands to pump ground waters, but the lift will be nearly as great as from the river and the water will be of inferior quality, since all of the west-side ground waters contain notable quantities of salts and some of them approach the limit of usability for irrigation.

PUMPING PLANTS.

Pumping plants for irrigation were practically unknown in this county in 1906, when this investigation was made, but one or two being in operation. They are used, however, to supply the stations of the Pacific Coast Oil Co., the railroads, and the domestic supply for the city of Modesto. Ground waters are accessible with moderate lifts throughout the west half of the east slope of the valley, and as irrigation progresses under the gravity systems and the water plane rises, their development will become increasingly desirable as a means of drainage as well as a source of auxiliary or independent irrigation supply. That intensive cultivation and careful methods will make it as practicable here as it is elsewhere in the valley scarcely needs affirmation.

QUALITY OF GROUND WATER.

Though little land in Stanislaus County is irrigated by pumping it is apparent from conditions north and south of this county that ground water of good quality can be procured from wells 100 to 1,000 feet deep in the territory indicated as east of line C′C′ in Plate II (in pocket). Those that were tested average about 300 parts per

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	les.		Classification.			
	oba-ty of ssion e 2).	Alkali coefficient (k) (inches).	Mineral content.	Chemical character.	Quality for boilers.	Quality for irrigation.
Pacific Coast Oil Co	?	65	Moderate..	$Ca\text{-}CO_3$....	Poor.....	Good.
Chris Nickert	?	50	...do.....	...do.....	...do.....	Do.
J. M. Hammond	?	12	High.....	$Ca\text{-}SO_4$....	Very bad .	Fair.
Geo. Mundegle	?	16	...do.....	$Ca\text{-}CO_3$....	Bad.....	Do.
J. M. Ritchie	?	80	Moderate..	...do.....	...do.....	Good.
Do	?	80	...do.....	...do.....	...do.....	Do.
C. D. Elfers	?	30	High.....	...do.....	...do.....	Do.
R. H. Zaccarias	?	16	...do.....	$Ca\text{-}SO_4$....	...do.....	Fair.
M. Rogers	?	20	...do.....	...do.....	Poor.....	Good.
H. A. Bowman	C.	8	...do.....	Na-Cl.....	Bad.....	Fair.
District school	C.	60	Moderate..	$Ca\text{-}CO_3$....	Poor.....	Good.
Pacific Coast Oil Co	.	25	High.....	$Ca\text{-}SO_4$....	Very bad..	Do.
Mr. Love	.	60	...do.....	...do.....	Poor.....	Do.
J. H. Elfers	?	20	...do.....	$Ca\text{-}CO_3$....	...do.....	Do.
Mr. Stonesypher	?	45	...do.....	$Ca\text{-}SO_4$....	Very bad..	Do.
Jasper Stuhr	?	140	Moderate..	$Ca\text{-}CO_3$....	Poor.....	Do.
T. Snedigar	?	25	...do.....	...do.....	...do.....	Do.
G. W. Parker	C.	140	Low.....	...do.....	Good.....	Do.
Mrs. I. T. Bangs	?	50	Moderate..	...do.....	Poor.....	Do.
E. A. Johnson	C.	50	...do.....	...do.....	Fair.....	Do.
D. S. Christman	?	17	...do.....	...do.....	Poor.....	Fair.
A. L. Rutherford	C.	40	...do.....	...do.....	Fair.....	Good.
W. A. Reedy	C.	80	...do.....	...do.....	...do.....	Do.
J. N. Butts	C.	25	...do.....	$Na\text{-}CO_3$....	...do.....	Do.
C. Vincent	C.	60	...do.....	$Ca\text{-}CO_3$....	Poor.....	Do.
Mr. Sanders	.	3	High.....	Na-Cl.....	Very bad..	Poor.
Glenn Crow	.	7	...do.....	...do.....	...do.....	Fair.
J. S. Pike	?	8	...do.....	...do.....	Bad.....	Do.
James McDermott estate	.....	5	...do.....	...do.....	...do.....	Poor.
Newman Light & Power	?	5	...do.....	...do.....	Very bad..	Do.
J. B. Ames	C.	140	Moderate..	$Ca\text{-}CO_3$....	Fair.....	Good.
J. W. McHugh	?	140	Low.....	...do.....	...do.....	Do.
J. W. Derrdoff	?	80	Moderate..	...do.....	...do.....	Do.
J. M. Mackley	?	50	...do.....	...do.....	...do.....	Do.
S. E. Anderson	C.	35	...do.....	...do.....	Poor.....	Do.
Colony school district	C.	80	...do.....	...do.....	Fair.....	Do.
George Leclert	C.	100	...do.....	...do.....	...do.....	Do.
J. M. Finley	?	80	...do.....	...do.....	...do.....	Do.

Owner.	Classification.				Analyst.
	neral tent.	Chemical character.	Quality for boilers.	Quality for irrigation.	
Pacific Coast Oil Co.	erate .	$Ca\text{-}CO_3$....	Poor.....	Good..	Pacific Coast Oil Co.
W. G. Adams	Oct	...do.....	...do.....	Fair...	F. M. Eaton.
J. M. Hammond	Oct	$Ca\text{-}SO_4$....	Bad.....	...do...	Do.
Geo. Field	Oct	...do.....	Very bad..	...do...	Do.
Southern Pacific Co.	Apr	$Ca\text{-}CO_3$...	Poor.....	...do...	Southern Pacific Co.
Do	Apr	...do.....	...do.....	Good..	Do.
G. W. Parker	Oct	...do.....	Good	...do...	Do.
Modesto Water Co..	Jul erate	Na-Cl.....	Fair.....	Fair...	Do.
Newman Water Co..	Oct	...do.....	Very bad..	Poor..	F. M. Eaton.
Southern Pacific Co.	Ma	...do.....	...do.....	Fair...	Southern Pacific Co.
S. Newman	Oct	$Ca\text{-}CO_3$...	Bad.....	...do...	F. M. Eaton.
S. F. Capps	Oct erate	...do.....	Fair.....	Good..	Do.
Oakdale Water Co..	Oct	...do.....	...do.....	...do...	Southern Pacific Co.
Southern Pacific Co.	Apr	$Na\text{-}CO_3$...	...do.....	...do...	Do.

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million in total solids and 140 parts in total hardness, and nearly all are classed as good for irrigation; they would form some scale in boilers, but they are not corrosive and would not cause foaming. Waters deeper than 1,200 feet are probably salty. As no wells more than 200 feet deep on the east side of the county could be tested, the composition of the deep waters between San Joaquin River and the location shown by line C'C' is unknown. Some of the supplies from wells 30 to 100 feet deep west and south of Modesto and close to the axis are high in chlorides, and those from wells 300 to 600 feet deep in Stevinson Colony are salty, as is also that from the 480-foot well at Crows Landing. Any artesian waters in Stanislaus County, therefore, would probably be salty and would range from fair to bad for irrigation, according to their concentration.

The west-side waters are irregular in composition, except that all contain notable amounts of sulphate. All those tested near Newman are highly mineralized sodium chloride waters of poor quality, the shallow supplies not being essentially different from those at 300 to 400 feet. Several waters with carbonate predominating were found at Crows Landing and at Westley, but they would also deposit large quantities of hard scale in boilers. No supplies that would be considered unfit for irrigation were found north of Newman, though the artesian supply near Crows Landing is of rather doubtful quality. Water from wells 80 to 300 or 400 feet deep west of the artesian area could probably be utilized for irrigation. The water from San Joaquin River is acceptable for irrigation.

Tables 40 and 41 indicate the composition and usefulness of the ground waters in Stanislaus County that were analyzed or assayed.

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WELL RECORDS.

The data assembled in the following tables of wells in Stanislaus County were secured by W. N. White in 1906, and therefore do not record developments since that date.

TABLE 42.—*Records of wells in Stanislaus County.*

Owner.	Location.	Year completed.	Type and diameter of well.	Depth of well.	Depth to water.	Temperature of water.	Method of lift.	Use of water.[a]	Yield.	Cost of well.	Cost of machinery.
				Feet.	*Feet.*	° *F.*			*Miner's inches.*		
Rhodes Bros.	Sec. 2, T. 1 N., R. 10 E.	1882	Bored, 4 inches.	16	2	.....	Wind	D, S.	.....	.....	$160
Henry McDevitt	Sec. 11, T. 1 N., R. 10E.	1873	Dug, 5 feet	158	152	.....	do	D, S.	.....	.....	[b] 400
D. E. Kelliher	Sec. 35, T. 1 N., R. 10 E.	1892	Dug	70	65	69	do	D, S.	.....	.....	.....
Luke Nolan	Sec. 34, T. 1 N., R. 10 E.	1904	Bored, 7 inches	140	72	.....	do	D, S.	.....	$110	.....
P. L. Ford	Sec. 33, T. 1 N., R. 10 E.	1866	Dug, 4 feet	77	71.5	70	do	D, S.	.....	.....	125
F. L. Griffin	Sec. 32, T. 1 N., R. 10 E.	Old.	do	110	72	.....	do	D, S.	.....	.....	.....
San Francisco Savings Bank	Sec. 10, T. 1 S., R. 10 E.	1881?	Dug	175	131	.....	do	D, S.	.....	.....	.....
Mr. Aldrich	Sec. 18, T. 1 S., R. 10 E.	Old.	do	160	100	.....	do	D, S.	.....	.....	.....
Mr. Spanker	Sec. 16, T. 1 S., R. 10 E.	Old.	do	125	118.2	.....	do	D, S.	.....	.....	.....
Richard Steick	Sec. 19, T. 1 S., R. 10 E.	1905	Bored, 8 inches	90	64	.....	do	D, S.	.....	52	30
R. Reid	Sec. 21, T. 1 S., R. 10 E.	1885?	Dug, 4 feet	110	100	.....	do	D, S.	.....	.....	.....
S. F. Capps	Sec. 27, T. 1 S., R. 10 E.	1866?	do	114	106.3	.....	do	D, S.	.....	.....	.....
H. L. Heinricks	Sec. 29, T. 1 S., R. 10 E.	1904	Bored, 2½ inches	170	.....	.....	do	D, S.	.....	.....	26
Harry Bates	Sec. 34, T. 1 S., R. 10 E.	Old.	Dug, 4 feet	100	89	.....	do	N	.....	.....	.....
E. Williams	Sec. 6, T. 2 S., R. 11 E.	.....	do	48	42	.....	Hand	S	.....	.....	.....
James McLeod	Sec. 5, T. 2 S., R. 11 E.	1882	do	276	24.1	61	Wind	D, S.	.....	26	50
J. D. Bently	Sec. 7, T. 2 S., R. 11 E.	1871	Dug, 3 feet	165	118	.....	do	D, S.	.....	.....	.....
	Sec. 9, T. 2 S., R. 11 E.	.....	do	+ 75	62.5	.....	do	D, S.	.....	.....	.....
L. C. Walter	Sec. 13, T. 2 S., R. 11 E.	1885?	do	135	128	.....	do	D, S.	.....	.....	.....
William N. Adams	Sec. 17, T. 2 S., R. 11 E.	Old.	Dug, 4 feet	117	99	.....	do	D, S.	.....	.....	.....
J. H. Mowry	Sec. 22, T. 2 S., R. 11 E.	Old.	Dug, 3 feet	160	149	.....	do	D, S.	.....	.....	.....
Mrs. Kearney	Sec. 20, T. 2 S., R. 11 E.	Old.	Dug, 5 feet	140	127	.....	do	D, S.	.....	280	100
M. B. Root	Sec. 28, T. 2 S., R. 11 E.	1876	Dug, 4 feet	150	140	.....	do	D, S.	.....	.....	107
H. D. Laughlin	Sec. 30, T. 2 S., R. 11 E.	1898	Dug, 3 feet	+100	105	.....	do	D, S.	.....	.....	.....
E. J. Blankenship	Sec. 14, T. 2 S., R. 10 E.	1866	Dug, 5 feet	150	142	.....	do	D, I.	.....	.....	.....
F. M. Cottle	Sec. 12, T. 2 S., R. 10 E.	1880	Dug, 4 feet	60	55	.....	do	D, S.	.....	.....	.....
John Clark	Sec. 1, T. 2 S., R. 10 E.	Old.	Dug, 5 feet	129	120	.....	do	D, S.	.....	.....	.....
W. C. Carmichael	Sec. 4, T. 2 S., R. 10 E.	1876	Dug, 4 feet	102	90	.....	do	D, S.	.....	.....	50
J. B. Ames	Sec. 11, T. 2 S., R. 10 E.	1901	Bored, 7 inches	140	40	.....	do	D, S.	.....	.....	85
J. M. Haray	Sec. 15, T. 2 S., R. 10 E.	1905	Bored, 3 inches	145	.....	.....	do	D	.....	.....	.....
E. F. Coleman	Sec. 17, T. 2 S., R. 10 E.	.....	Dug, 3 feet	50	40.3	.....	do	D	.....	.....	50
J. W. McHugh	Sec. 26, T. 2 S., R. 10 E.	1881	Dug, 4 feet	135	110	.....	do	D	.....	100	175

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F. H. Heckman	Sec. 35, T. 2 S., R. 10 E.	1891	....do	98	90		....do	D, S, I		140	160
R. J. McKimmon	Sec. 34, T. 2 S., R. 10 E.	1897?	Bored, 7 inches	106	75.4		....do	D, S			
O. Snediger	Sec. 29, T. 2 S., R. 10 E.	1876	Dug, 4 feet	100	88	71	Wind and gas	D, S			240
	Sec. 36, T. 2 S., R. 9 E.	Old.	Bored, 7 inches	75	58		Wind	S			
T. Snediger	Sec. 25, T. 2 S., R. 9 E.		Dug, 4 feet	+ 90	63		....do	D			
M. J. Kline	Sec. 27, T. 2 S., R. 9 E.	1906	Bored, 6 inches	75	35		Hand	D		37	20
Frank Bennett	Sec. 29, T. 2 S., R. 9 E.	1906	Bored, 7 inches	48	27.7		....do	D		55	12
I. S. Hughes	Sec. 30, T. 2 S., R. 9 E.	1880	Bored	80	20		Wind	D, S		75	100
L. P. Jacobson	....do	1888	Bored, 8 inches	75	35		....do	D, S		100	70
W. J. Keeley	Sec. 31, T. 2 S., R. 9 E.	1861?	Dug, 3 feet		24.5		....do	D, S			74
W. E. Strother	Sec. 26, T. 2 S., R. 8 E.	1898	Bored	84	29.5		....do	D, S, I			
T. S. Hayes	Sec. 33, T. 2 S., R. 8 E.	Old.	Bored, 7 inches	26	13.9		....do	D			
R. L. Miller	Sec. 32, T. 2 S., R. 8 E.	1895?	Bored, 10 inches	32	11.5		....do	D		40	50
J. E. Kernan	Sec. 31, T. 2 S., R. 8 E.	1881	Bored, 7 inches	30	3.9		....do	D			120
Mrs. Carson	Sec. 12, T. 3 S., R. 7 E.	1886?	....do	32	7.8		....do	D			
D. H. Pierson	....do	1891	Bored	25	12		....do	D			
J. H. Terry	Sec. 13, T. 3 S., R. 7 E.	Old.	Bored, 8 inches	85	8		....do	D, I		100	100
J. N. Nelson	....do	1895?	Bored, 7 inches	58	5	69	....do	D, S			40
A. Gates	Sec. 22, T. 3 S., R. 7 E.		Bored, 6 inches	99	9.2	70	....do	D, S			
Jacob Ohm	El Pescadero (Grimes)		Bored, 7 inches	+100	49		....do	D			
Mrs. J. W. Hawley	....do	1886	Bored	110	16		....do	D, I		165	
Samuel Gates	Sec. 26, T. 3 S., R. 7 E.	1876	Bored, 8 inches	72	11		....do	D, S		80	150
W. G. Adams	Sec. 36, T. 3 S., R. 7 E.	1885?	Bored, 7 inches		14.6		....do	D, S			50
C. D. Butter	Sec. 29, T. 3 S., R. 8 E.		....do	35	8.5	68	....do	D, S			
H. Winters	....do	Old.	....do	130	5.8		....do	D, S			
H. A. Bowman	Sec. 28, T. 3 S., R. 8 E.	Old.	....do	36	20		....do	D, S			
John Murphy	....do	Old.	....do	49	12	68	....do	S			
C. M. Beckworth	Sec. 17, T. 3 S., R. 8 E.	1891?	....do	85	13.5		....do	D			
W. W. Bacon	Sec. 8, T. 3 S., R. 8 E.	1906	....do	63	9.7	69	Gas	S, I	25	95	250
V. B. Dale	Sec. 2, T. 3 S., R. 8 E.	1869	Dug, 5 feet	26	20.7		Wind	D			
R. W. Chappel	Sec. 1, T. 3 S., R. 8 E.	1889?	Bored, 7 inches	90	16		....do	D, S		100	
E. S. Prescott	Sec. 7, T. 3 S., R. 9 E.	1904	Bored	65	35	70	....do	D, S		32	90
Covell Bros	Sec. 11, T. 3 S., R. 8 E.	1903	....do	49	20		....do	D, S		44	50
J. T. Gish	Sec. 14, T. 3 S., R. 8 E.	1903	Bored, 7 inches	42	18					22	50
R. R. Cartwright	Sec. 13, T. 3 S., R. 8 E.	1904	Bored, 7 inches	66	9	69	....do	D, S		55	55
Mrs. Williams	Sec. 24, T. 3 S., R. 8 E.	1875?	....do	50	17	69	....do	D, I			
A. Halsall	Sec. 22, T. 3 S., R. 8 E.	1903	....do	56	8	70	....do	D, S			[b] 110
C. E. Clarke	....do	1904	Bored, 6 inches	56	16		....do	D, S, I		49	55
George Morgan	Sec. 30, T. 3 S., R. 9 E.	1904	Bored, 7 inches	150	14	70	....do	D, S, I			
C. C. McCarty	Sec. 31, T. 3 S., R. 9 E.	1905	[c]	98	30	72	....do	D, S, I		100	60
Modesto Water Co	Modesto	1889		195				D			
Do	....do			257	33		Electric		[d] 125		[b] 63,000
R. Woods	Sec. 28, T. 3 S., R. 9 E.	Old.	Bored, 7 inches	+ 43	32.5		Wind	D, S			40
D. S. Christman	Sec. 32, T. 3 S., R. 9 E.	Old.	Dug, 3 feet	100	29.8		....do	D			
Stanislaus County	....do	1875?	Bored, 10 inches	90	30		....do	D, S			
F. A. Cressey	Modesto	1902	[e]	186	277		Electric	D	133		10,000
Mr. McMahan	Sec. 21, T. 3 S., R. 9 E.	Old.	Dug, 3 feet	50	22		Wind	D			
Mrr. I. T. Bangs	Sec. 5, T. 3 S., R. 9 E.		Dug and bored, 8 inches	100	29		....do	D, I			

[a] D, domestic; S, stock; I, irrigation; B, boilers; N, not used.
[b] Cost of well and equipment combined.
[c] Dug well 33 feet deep; three 12-inch wells 195 feet deep.
[d] Yield estimated or statement of owner taken.
[e] Dug well 32 feet deep; with 10-inch well in bottom 154 feet deep.

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TABLE 42.—*Records of wells in Stanislaus County*—Continued.

Owner.	Location.	Year completed.	Type and diameter of well.	Depth of well.	Depth to water.	Temperature of water.	Method of lift.	Use of water.	Yield.	Cost of well.	Cost of machinery.
				Feet.	*Feet.*	° *F.*			*Miner's inches.*		
R. Coffee	Sec. 2, T. 3 S., R. 9 E.	Old.	Bored, 7 inches	65	34.5		Wind	D, S			
H. W. Patterson	Sec. 1, T. 3 S., R. 9 E.	1895	Dug, 5 by 5 feet	50	39.9	78	do	D, S			$50
Cole school district	Sec. 12, T. 3 S., R. 9 E.	1886?	Bored, 7 inches	48	37.5	69	do	D			
Anna M. Halverson	Sec. 11, T. 3 S., R. 9 E.	1886	do	70	34.7		do	D, S			
Samuel K. Anderson	Sec. 15, T. 3 S., R. 9 E.	1904	do	98	33	70	Hand	D, S			
John Adams	Sec. 13, T. 3 S., R. 9 E.	1878	Dug, 5 feet	48	35.5		Wind	D, S			55
W. C. Keeley	Sec. 24, T. 3 S., R. 9 E.	Old.	Bored, 7 inches	60	40		do	D, S			
H. M. Graham	Sec. 23, T. 3 S., R. 9 E.	Old.	do	75	35		do	D, S			
George H. Flanders	Sec. 27, T. 3 S., R. 9 E.	1905	do	74	52.8	70	Hand	D			a 95
J. A. Saferite	Sec. 28, T. 3 S., R. 9 E.	1856	Dug, 4 by 4 feet	45	35		Wind	D, S			40
Elder Pittman	Sec. 26, T. 3 S., R. 9 E.	1903	Bored, 7 inches	120	35.7		do	D, S		$90	85
H. T. Crow	Sec. 25, T. 3 S., R. 9 E.	1886	Bored	65	39	69	do	D, S			
Garner school district	Sec. 30, T. 3 S., R. 10 E.		Bored, 7 inches	80	44.4		do	D			
Mary A. Torbert	Sec. 31, T. 3 S., R. 10 E.	1905	do	128	57.5		do	D, S		115	55
G. J. Bentley	Sec. 18, T. 3 S., R. 10 E.	1904	do	92	36.7	70	do	D, S			
F. B. Lord	Sec. 6, T. 3 S., R. 10 E.	Old.	do	90	30		do	D, S			
A. D. Medford	Sec. 5, T. 3 S., R. 10 E.	1905	do	92			do	D		72	25
J. H. Johnson	Sec. 3, T. 3 S., R. 10 E.	Old.	Dug, 4 feet	90	78		do	D, S			
F. H. Dinkleman	Sec. 15, T. 3 S., R. 10 E.	1898?	Bored, 7 inches	100	74	69	do	D, S			70
Milnes school district	Sec. 9, T. 3 S., R. 10 E.		do	82	62.3		do	D			
	Sec. 33, T. 3 S., R. 10 E.	1891	do	137	97		do	D, S			
S. Spyres	Sec. 27, T. 3 S., R. 10 E.	1904	do	106	63		do	D, S		86	65
G. P. Schafer	Sec. 26, T. 3 S., R. 10 E.		do	125	65?		do	D, S			70
A. Shearer	Sec. 30, T. 3 S., R. 11 E.	1876?	Dug and bored, 7 inches.	116	68.4		do	D, S			
W. H. Palmer	Sec. 18, T. 3 S., R. 11 E.	1872	Dug	100	70		do	D, S			
George Leclert	Sec. 4, T. 3 S., R. 11 E.	Old.		145	126		do	D, S			
Henry Schadlich	Sec. 3, T. 3 S., R. 11 E.	Old.	Dug, 5 feet	+ 100	89.6		do	D			
T. K. Beard	Sec. 9, T. 3 S., R. 11 E.	Old.	Dug, 4 feet	130	117		do	D, S			
Do	Sec. 17, T. 3 S., R. 11 E.	1885?	Dug, 3 feet	90	78		do	D, S			
Charles Eardley	Sec. 20, T. 3 S., R. 11 E.	1866	Bored	90	36		do	D, S			
S. E. Welch	Sec. 29, T. 3 S., R. 11 E.	1876	do	150	84		do	D, S			85
J. M. Finley	Sec. 8, T. 3 S., R. 11 E.	1891?	Dug	150	90		do	D, S			
	Sec. 28, T. 3 S., R. 11 E.	Old.	Bored, 7 inches	87	75		do	D, S			
Alice D. Jones	Sec. 7, T. 4 S., R. 12 E.	1903	do	108	51		do	D, S			
	Sec. 9, T. 4 S., R. 12 E.	Old.	do	190?	160		do	D, S			
Mr. Hawkins	Sec. 16, T. 4 S., R. 12 E.	Old.	Dug, 4 feet	100	91		do	D, S			
	Sec. 15, T. 4 S., R. 12 E.	Old.	do	85	77		do	D, S			
Jacob Oleson	Sec. 22, T. 4 S., R. 12 E.	1886	Bored, 7 inches	186	101		do	D, S			
Dickinson school district	Sec. 25, T. 4 S., R. 12 E.	1897?	do	+ 200	197		do	D			

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I. Fox	Sec. 26, T. 4 S., R. 12 E.	1875?	....do	190	159		....do	D,S			
J. E. Anderson	Sec. 27, T. 4 S., R. 12 E.	1876	....do	200?	151		....do	D,S			
Dolan estate	Sec. 28, T. 4 S., R. 12 E.	1885?	....do	160	135		....do	D,S			175
A. J. Barnes	Sec. 20, T. 4 S., R. 12 E.	1885?	....do	160	139		....do	D,S			150
Charles Swan	Sec. 32, T. 4 S., R. 12 E.	Old.	Dug, 3 feet	115	107		....do	D,S			90
W. G. Bledsoe	Sec. 36, T. 4 S., R. 11 E.	1898	Bored, 7 inches	150	110		....do	D			125
J. P. Ross	Sec. 25, T. 4 S., R. 11 E.	1898	....do	138	98		....do	D,S		105	160
James B. Wallis	Sec. 23, T. 4 S., R. 11 E.	1906	....do	122	96		....do	D,S		75	170
W. W. Hall	Sec. 14, T. 4 S., R. 11 E.	1890	....do	160	98		....do	D,S			
Clark Bradley	Sec. 10, T. 4 S., R. 11 E.	1905	....do	90	62		....do	D,S			
The Grange Co	Sec. 3, T. 4 S., R. 11 E.	1891	....do	110	98?		....do	S			65
Gilbert Gilbertson	Sec. 4, T. 4 S., R. 11 E.	1904	....do	112	68		....do	D,S			50
	Sec. 9, T. 4 S., R. 11 E.		....do	111	52.5		....do	D,S			
L. M. Hickman	Sec. 21, T. 4 S., R. 11 E.	1889?	Bored, 8 inches	1,600?	64.3		Not raised	N			
Do	....do		....do	90	65		Wind	D,S			
Do	Sec. 27, T. 4 S., R. 11 E.	1882	Bored, 7 inches	139	68		....do	D,S			
Balfour, Guthrie & Co	Sec. 35, T. 4 S., R. 11 E.	1888?	....do	150	135		....do	D,S			
G. R. Crosby	Sec. 29, T. 4 S., R. 11 E.	1906	....do	96	28		Hand	D			
A. M. Morton	Sec. 31, T. 4 S., R. 11 E.	1902	....do	96	36	69	....do	D,S		60	
Mr. Tomlinson	Sec. 36, T. 4 S., R. 10 E.	1885?	....do	+ 42	37		Wind	S			
James Klough	Sec. 14, T. 4 S., R. 10 E.	1890?	....do		56		....do	S			
Henry Sanderson	Sec. 9, T. 4 S., R. 10 E.	1902	....do	178	30		....do	D,S		110	80
H. C. Baskey	....do	1905	....do	82	46		....do	D,S		60	45
W. S. Parks	Sec. 6, T. 4 S., R. 10 E.	1898	....do	200	30		....do	D,S			45
The Grange Co	Sec. 9, T. 4 S., R. 10 E.	1897?	....do	112	40.2		....do	N		85	85
H. Hughson	Sec. 16, T. 4 S., R. 10 E.	Old.	....do	62	40		....do	D,S			
E. Brown	Sec. 17, T. 4 S., R. 10 E.	1903	....do	72	30		....do	D,S		55	75
J. McEfee	....do	1905	....do	38	12.3	66	Hand	D			
George Tulley	Sec. 34, T. 4 S., R. 10 E.	Old.	....do	67	29.3	68	Wind	D			
J. W. Bauman	Sec. 28, T. 4 S., R. 10 E.	1905	....do	98	24	68	Hand	D,S			
J. M. Mackley	Sec. 32, T. 4 S., R. 10 E.	1905	Bored, 4 inches	60	20		Wind	D,S			45
G. A. Brown	Sec. 32, T. 4 S., R. 10 E.	1876?	Bored, 7 inches	60	20	67	....do	D			
E. B. Foote	Sec. 31, T. 4 S., R. 10 E.	1904	....do	77	16	70	....do	D		60	45
B. F. Barrows	Sec. 24, T. 4 S., R. 9 E.	1903	Bored	34	18		....do	D,S			
A. J. Ray	Sec. 11, T. 4 S., R. 9 E.	1902	Bored, 7 inches	130	28	69	....do	D,S			
S. Zinn	Sec. 3, T. 4 S., R. 9 E.	1903	Bored, 6 inches	79	17		....do	D,S		57	45
T. H. Davies	Sec. 4, T. 4 S., R. 9 E.	1901	Bored, 7 inches	36	23.9	69	....do	D,S			65
J. T. Kerr	Sec. 5, T. 4 S., R. 9 E.	1902	....do	128	37.5		....do	D,S		104	75
James Watson	Sec. 6, T. 4 S., R. 9 E.		....do	90	30+		....do	D,S			100
A. L. Rutherford	Sec. 8, T. 4 S., R. 9 E.	1898	....do	147	12.8		....do	D,S		147	
Ceres cemetery	Sec. 4, T. 4 S., R. 9 E.	1895	....do	46	10.7		....do	I			
B. B. Wilson	Sec. 14, T. 4 S., R. 9 E.	1900	Bored	89	15		Hand	D			a 100
E. P. Hatch	Sec. 22, T. 4 S., R. 9 E.	Old.	Bored, 7 inches	+33	7.1		Wind	D,S			
Mr. Gray	Sec. 15, T. 4 S., R. 9 E.	1904	....do	86	6	69	....do	D,S			
F. Cornwall	Sec. 17, T. 4 S., R. 9 E.	1902	....do	80	11.7	69	....do	D,S			
Thomas Caswell	Sec. 18, T. 4 S., R. 9 E.	1902?	Dug, 3 by 3 feet	21	13.8	68	Hand	D,S			
George Davis	Sec. 19, T. 4 S., R. 9 E.	1904	Bored, 7 inches	55	15		Wind	D,S			75
Thomas Strop	Sec. 20, T. 4 S., R. 9 E.	1906	....do	90	12	69	Hand	D,S			
J. N. Butts	Sec. 28, T. 4 S., R. 9 E.	1904	....do	91	8.7		Wind	D,S			
E. G. Stone	Sec. 23, T. 4 S., R. 9 E.	1901	Bored	90	6		....do	D,S		70	75

a Cost of well and equipment combined.

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TABLE 42.—*Records of wells in Stanislaus County*—Continued.

Owner.	Location.	Year completed.	Type and diameter of well.	Depth of well.	Depth to water.	Temperature of water.	Method of lift.	Use of water.	Yield.	Cost of well.	Cost of machinery.
				Feet.	*Feet.*	° *F.*			*Miner's inches.*		
W. V. Morris	Sec. 26, T. 4 S., R. 9 E.	1905	Bored, 7 inches	84	16	69	Hand	D, S		$71	
Mrs. W. C. Elliott	Sec. 34, T. 4 S., R. 9 E.	1886?	do	57	10		Wind	D, S			
Judge Hewell	do	1882	do	55	10	69	Hand	D			
A. N. Silvera	Sec. 33, T. 4 S., R. 9 E.	1903	do	52	6.5	69	do	D			
J. L. Dunn	Sec. 32, T. 4 S., R. 9 E.	1904	do	38	7	69	do	D		35	
R. R. More	Sec. 33, T. 4 S., R. 9 E.	1886	do	54	7.5		Wind	D, S			$80
F. C. Chapman	Sec. 30, T. 4 S., R. 9 E.	1876?	do	65?	10		do	D, S			75
J. H. Courtney	Sec. 13, T. 4 S., R. 8 E.	1902?		103	15.5	68	do	D, S			
Uril Bros	Sec. 1, T. 4 S., R. 8 E.	1895?	Bored, 7 inches	90	30		do	D			50
J. C. Batchelder	Sec. 4, T. 4 S., R. 8 E.		do	65			do	D, S			
District school	Sec. 8, T. 4 S., R. 8 E.	Old.	do	42	17		Hand	D			
Union Savings Bank	Sec. 18, T. 4 S., R. 8 E.	1906	do	35?		68	Wind	D, S			50
G. W. Moore estate	Sec. 30, T. 4 S., R. 8 E.	1901?	do	50	20		do	D, S			
Ed. Brush	do		Dug, 3 feet	19	8.2		do	D, S			
O. H. Halverson	Sec. 27, T. 4 S., R. 8 E.	Old.	Bored, 7 inches	+49	17+	68	do	D, S			
Thomas Coswell	Sec. 14, T. 4 S., R. 8 E.	Old.	do	60	18.3	70	do	D			
J. M. Moyle	Sec. 26, T. 4 S., R. 8 E.	Old.	do	50	9.1	69	do	D, S			
Osman Johnson	Sec. 35, T. 4 S., R. 8 E.	1897?	do	80	9.4		do	D, S			
S. Elbrush	Sec. 34, T. 4 S., R. 8 E.	Old.	do		12.3	70	do	D, S			
Laud estate	El Pescadero (Grimes).	1868	do	45	25.5		do	D, S			
C. B. Taylor	Sec. 27, T. 4 S., R. 7 E.	1890?	Bored, 6 inches	45	10		Hand	D		75	4
Smith estate	El Pescadero (Grimes).	1881?	Bored	68	48		Wind	D, S			
Balfour Guthrie Co	do	1902?	do	130	35		do	D, S			
Welty Bros	Sec. 3, T. 4 S., R. 6 E.	1890	Bored, 8 inches	140	95		do	D, S			
Chris Nickert	Sec. 12, T. 4 S., R. 6 E.	1897	Bored, 7 inches	100	60		do	D, S			a 200
J. W. Purnell	Sec. 14, T. 4 S., R. 6 E.	1878?	Dug, 4 feet	76	71.5		do	D, S			
John Gaffery	Sec. 8, T. 4 S., R. 6 E.	1876?	Dug	180	170		do	D, S			
Frank Carpenter	Sec. 24, T. 4 S., R. 6 E.	1895	Bored, 7 inches	165	100		do	D, S			
G. W. Hamilton	Sec. 26, T. 4 S., R. 6 E.	1905	Bored, 5 inches	170	150		do	D		170	200
J. M. Hammond	Sec. 28, T. 4 S., R. 7 E.	1897	Bored, 7 inches	125	65		do	D			150
Southern Pacific Co	El Pescadero (Grimes).	1887?	Bored, 10 inches	200	54		Gas	B	6		
Mrs. E. J. McDonald	Sec. 4, T. 5 S., R. 7 E.	1881	Bored	180	80		Wind	D, S			
Charles D. Elfers	Sec. 8, T. 5 S., R. 7 E.	1892	Bored, 8 inches	180	130		do	D, S		200	230
J. M. Hammond	Sec. 10, T. 5 S., R. 7 E.	1887	Dug	110	105.5		do	D, S		110	188
Elmer H. Baldwin	Sec. 14, T. 5 S., R. 7 E.	1886	Bored, 8 inches	140		64	do	D, S, I.			200
M. Rogers	Sec. 23, T. 5 S., R. 7 E.	1900	Bored, 6 inches	196	80		do	D, S		196	95
John Outhet	Sec. 26, T. 5 S., R. 7 E.	1902	do	170	50		do	D, S		160	200
Mrs. B. Morton	Sec. 36, T. 5 S., R. 7 E.	Old.	Bored, 7 inches	151	95.2		do	D, S			
Pacific Coast Oil Co.[b]	Sec. 31, T. 5 S., R. 8 E.	1904	Dug and bored, 10 inches.	223	80		Steam	B			

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A. D. Elfers	Sec. 6, T. 6 S., R. 8 E.	1895	Bored, 11 inches	228	90		Wind	D, S.			
Zaccarias estate	do		Bored, 7 inches	170	133		do	D, S.			
Mr. Love	Sec. 5, T. 6 S., R. 8 E.	1888?	do	120	63		do	S.			
L. McCauley	Sec. 8, T. 6 S., R. 8 E.	1886	do	140	66		do	S.			
R. B. Marshall	Sec. 10, T. 6 S., R. 8 E.		do	100	47	67	do	S.			
	Del Puerto Orestimba.	Old.	do	47	13.5		do	S.			
	do		do	48	10.5		do	S.			
Glenn Crow	do	1886?	Bored, 8 inches	480?	0	78	Artesian	S.	Small		
Do	do	Old.	Dug, 3 feet	20	14		Wind	D, S.			
B. F. McCullough	do	1903?	Bored, 7 inches	100?	13	66	do	D, S.			
H. F. Hoskin	do	1898?	do	160	14.5	66	do	D, S.			
Crow estate	Sec. 17, T. 6 S., R. 8 E.		do	90	34.5		do	D, S.			
George Fink	Sec. 21, T. 6 S., R. 8 E.	1881?	Bored, 8 inches	+93	91		do	D, S.			
G. W. McGinnis	Sec. 22, T. 6 S., R. 8 E.	1906	Bored, 7 inches	248	44.5		do	S.			
J. H. Elfers	Sec. 27, T. 6 S., R. 8 E.	1889	do	90	38.3		do	D, S.			
P. W. Witten	Sec. 26, T. 6 S., R. 8 E.	1900	do	120	11.7		do [b]	D, S.			
John Barber	Del Puerto Orestimba.	Old.	do	50	10	66	do	D, S.			
M. V. Alvis	do	1904?		123	12	60	do	D, S.			$75
	do		Bored, 7 inches	102	11		do	D, S.			
Mr. Stonesypher	do		do	30	15.7		do	D, S.			
S. J. Reed	Sec. 4, T. 7 S., R. 8 E.	Old.	do	82	57		do	D, S.			
Simon Newman Co	Sec. 5, T. 7 S., R. 8 E.	Old.	do	160	70		do	D, S.			
John Elford	Sec. 10, T. 7 S., R. 8 E.	1900	do	70	58		do	D, S.			
E. E. Town	Sec. 9, T. 7 S., R. 8 E.	1883?	Dug, 4 by 4 feet	22	9.6	67	do	D, S.			
A. G. Stonesypher	Sec. 17, T. 7 S., R. 8 E.	1885	Dug, 3 by 3 feet	15	9		do	D, S.			
Jules Cain	Sec. 10, T. 7 S., R. 8 E.	1885?	Bored, 7 inches	73	58		do	D, S.			
C. Jensen	Sec. 23, T. 7 S., R. 8 E.	1886	Dug and bored, 7 inches.	118	35.5		do	D, S.			
H. E. Kinkaid	Sec. 26, T. 7 S., R. 8 E.	1892	Bored, 7 inches	96	35		do	D, S.			72
Frank Dennis	Sec. 24, T. 7 S., R. 8 E.	1903	do	60?	6	78	do	D, S.			
G. Savage	Sec. 19, T. 7 S., R. 9 E.	1906		60	4	65	Hand	D, S.			
Newman Water Co	Newman	1888	Bored, 8 inches	398	6			D.			
Do	do		do	396	6		Steam	D.	7		
Southern Pacific Co	do	1887	do	392	6		Gas	B.	13		
Mrs. Virginia Sherman	Del Puerto Orestimba.	1886	Bored, 7 inches	54	5	67	Wind	D, S.			
Priscilla Lundy	do	1888	do	78	4		do	D, S.			
A. Sado	do	Old.	do		4	68	do	D, S.			
A. Barbour	do		do	150	5		do	D, S.			
Simon Newman	Sec. 13, T. 7 S., R. 8 E.	Old.	do	32	13.4		do	D, S.			
Newman cemetery	Sec. 14, T. 7 S., R. 8 E.	1896	do	50	32.2		do	I.			
J. L. Kinnear	Del Puerto Orestimba.	1895?	Bored, 8 inches		0	76	Artesian	D, S.	5		
James McDermott estate	do	1904	do	285	0	76	do	I.			
B. Oleson	Sec. 7, T. 7 S., R. 9 E.	1900	Bored, 7 inches	80	5	77	Wind	D, S.			75
W. H. McClintock	Del Puerto Orestimba.	1893	do	56	3.5	68	Hand	D, S.			
J. J. Stevison	do	1881?	Bored, 8 inches	350?	0	73	Artesian	D, S.	b 1		
McCabe Bros	Sec. 6, T. 5 S., R. 9 E.	1891?	Bored, 7 inches	45	7.2		Wind	D, S.			90
M. McPhersons	Sec. 8, T. 5 S., R. 9 E.		Bored, 9½ inches	40?	3.5			N.			
Wren & Co	Sec. 16, T. 5 S., R. 9 E.	1881?	Bored, 7 inches	60?	8.5		Wind	D, S.			
Central school district	Sec. 11, T. 5 S., R. 9 E.	1904	do	38	8		do	D.			55
D. H. Holland	Sec. 12, T. 5 S., R. 9 E.	1904	Dug, 3 feet	15	8.5	68	Hand	D.			

[a] Cost of well and equipment combined.

[b] Two wells.

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TABLE 42.—*Records of wells in Stanislaus County*—Continued.

Owner.	Location.	Year completed.	Type and diameter of well.	Depth of well.	Depth to water.	Temperature of water.	Method of lift.	Use of water.[a]	Yield.	Cost of well.	Cost of machinery.
				Feet.	*Feet.*	° *F.*			*Miner's inches.*		
John Service	Sec. 12, T. 5 S., R. 9 E.	1886?	Bored, 7 inches	60	10	.....	Wind	D, S.	.....	.....	.....
A. Hecht	Sec. 14, T. 5 S., R. 9 E.	Old.	....do	50	9.5	78	....do	S.	.....	.....	$50
Do	Sec. 25, T. 5 S., R. 9 E.	Old.	Dug, 3 feet	12	8	.....	Not raised	N.	.....	.....	.....
O. C. Ocken	Sec. 16, T. 5 S., R. 9 E.	1905	Bored, 7 inches	67	10	68	Hand	D.	.....	$66	.....
Woods estate	Sec. 20, T. 5 S., R. 9 E.	Old.	.....	59	7.5	.....	Wind	S.	.....	.....	50
Charles Gier	Sec. 27, T. 5 S., R. 9 E.	1881?	Bored, 6 inches	300?	0	74	Artesian	S.	3	.....	.....
Do	....do	Old.	Bored, 7 inches	57	6.8	69	Hand	D.	.....	.....	.....
G. W. Jenkins	Sec. 26, T. 5 S., R. 9 E.	1881?	....do	50	9.5	68	....do	D, S.	.....	.....	.....
J. T. Weakley	Sec. 25, T. 5 S., R. 9 E.	1905	....do	34	9.5	66	....do	D, S.	.....	.....	.....
A. B. Hill	Sec. 24, T. 5 S., R. 9 E.	1905	....do	20	9.2	68	Wind	D, S.	.....	.....	.....
S. E. Foster	Sec. 7, T. 5 S., R. 10 E.	1885?	....do	38	10.3	66	....do	D, S.	.....	.....	.....
S. E. Anderson	Sec. 8, T. 5 S., R. 10 E.	1902	....do	40	22	67	....do	D, S.	.....	30	45
W. H. Potts	Sec. 5, T. 5 S., R. 10 E.	1905	....do	50	9.8	68	Hand	D.	.....	.....	c 49
W. H. Thornberg	Sec. 10, T. 5 S., R. 10 E	1886?	....do	99	10	.....	Wind	D, S.	.....	.....	.....
L. E. Thornberg	Sec. 9, T. 5 S., R. 10 E.	1884	....do	105	11	.....	....do	D, S.	.....	.....	.....
Charles Crowell	Sec. 3, T. 5 S., R. 10 E.	Old.	....do	140	13	.....	....do	D, S.	.....	.....	55
L. F. Lewis	Sec. 1, T. 5 S., R. 10 E.	1884?	Bored	46	15	67	....do	D, S.	.....	.....	45
William Paul	....do	1906	Bored, 7 inches	+ 40	11.8	68	Hand	D.	.....	.....	.....
Manuel J. Gomez	Sec. 11, T. 5 S., R. 10 E.	1903	....do	48	8	69	....do	D.	.....	.....	.....
J. DeNair	Sec. 13, T. 5 S., R. 10 E.	1886?	....do	32	6	.....	Wind	D.	.....	.....	.....
Crane Bros	Sec. 14, T. 5 S., R. 10 E.	1901	....do	48?	4.3	68	....do	S.	.....	.....	.....
Gus Carlson	Sec. 23, T. 5 S., R. 10 E.	1904	....do	52	7.3	69	Hand	D.	.....	42	.....
Edwin Johnson	....do	1905	....do	80	9	.....	Wind	D, S.	.....	.....	.....
Henry Lundell	Sec. 15, T. 5 S., R. 10 E.	1902	....do	46	8	68	....do	D, S.	.....	.....	c 298
Manuel Perez	....do	1905	....do	50	8	68	Hand	D.	.....	30	.....
James S. Schenk	Sec. 16, T. 5 S., R. 10 E.	1905	....do	42	6	69	....do	D.	.....	.....	.....
August Warren	....do	1903	....do	40	9	.....	Wind	D, S.	.....	.....	.....
Colony district school	Sec. 17, T. 5 S., R. 10 E.	1901?	....do	60	7.5	.....	....do	D.	.....	.....	.....
William Fletcher	Sec. 21, T. 5 S., R. 10 E.	1906	....do	50	8	70	Hand	D.	.....	.....	.....
B. F. Lane	Sec. 28, T. 5 S., R. 10 E.	1901	....do	60?	6	.....	Wind	D, S.	.....	.....	.....
Mr. Bowman	Sec. 32, T. 5 S., R. 10 E.	.....	....do	28	6	69	Hand	D, S.	.....	.....	.....
Ed. Hill	Sec. 4, T. 6 S., R. 10 E.	1904	....do	46	7	69	Wind	D, S.	.....	46	50
J. A. Gomes	....do	1904	Bored	35	6	69	Hand	D.	.....	.....	.....
Mrs. Casey	Sec. 27, T. 6 S., R. 10 E.	1881?	Bored, 7 inches	60?	7	.....	Wind	D, S.	.....	.....	.....
Mr. Heney	Sec. 34, T. 5 S., R. 10 E.	Old.	....do	71	8.5	68	Hand	S.	.....	.....	.....
P. E. Oleson	Sec. 27, T. 5 S., R. 10 E.	1903	....do	104	9	70	....do	D, S.	.....	.....	.....
J. E. Arthur	Sec. 25, T. 5 S., R. 10 E.	1905	....do	50?	7.7	70	....do	D, S.	.....	.....	.....
J. N. Lester	Sec. 6, T. 5 S., R. 11 E.	1905	....do	121	22	.....	Wind	D.	.....	90	75
Santa Fe Ry. Co	....do	1897	Bored, 10 inches	190	30	.....	Steam	B.	b 6	.....	.....

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Nevin Bros.	Sec. 4, T. 5 S., R. 11 E.	Old.	Bored, 7 inches	+ 60	50		Wind	D, S.			
Fletcher Ryer	Sec. 8, T. 5 S., R. 11 E.	1891	do	60	50		do	D, S.			80
H. C. Hyde	Sec. 20, T. 5 S., R. 11 E.	1876?	do	90	9.2	68	do	D, S.			
Ralph Gladings	Sec. 16, T. 5 S., R. 11 E.	1881?	do	60	23		do	D, S.			
John Anderson	Sec. 20, T. 5 S., R. 11 E.	1880?	do	42	19		do	S.			
Mr. Huckman	Sec. 15, T. 5 S., R. 11 E.		do	100?	80		do	D, S.			
Do	Sec. 14, T. 5 S., R. 11 E.	1875?	do	98	88.4		do	S.			85

[a] Cost of well and equipment combined.

[b] Yield estimated or statement of owner taken.

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MERCED COUNTY.

GENERAL CONDITIONS.

Merced County extends entirely across the San Joaquin Valley and thus includes both east-side and west-side territory. The gradual amelioration northward of the aridity of the south end of the San Joaquin Valley becomes noticeable at this latitude; hence, the raising of grain without irrigation, which is possible on the east side as far south as Fresno County, is usually successful on the west side in the northern part of Merced County.

Irrigation by surface water is accomplished principally by the utilization of San Joaquin and Merced rivers. The lower line of the San Joaquin and Kings River canal, which leaves the river near Mendota in Fresno County, extends entirely across the west side of Merced County and into Stanislaus County. The high-line canal of the same system also extends from the southern to within a few miles of the northern edge of the county. This irrigation work commands the larger portion of the west-side plain. The zone of unwatered land, between the high-line canal and the foothills, is relatively narrow.

The most important east-side system is the Crocker-Huffman canal, which taps Merced River about 2 miles below Merced Falls and serves an extensive section east and north of the county seat. The Stevinson-Mitchell canal heads in San Joaquin River about 14 miles southwest of Merced and commands a belt from 3 to 4 miles wide between this point and the mouth of Merced River. The principal settlement below this canal, the Stevinson Colony, is between the lower Merced and the San Joaquin.

North of Merced River, the Turlock irrigation district extends into Merced County from Tuolumne County, in which lie the greater part of the lands covered by the system. In addition to these major systems, there are a number of minor canals along the Merced River bottoms. On the whole, however, the county is thinly settled and but a small portion of it is under irrigation. Perhaps three-fourths of the valley lands are devoted to dry farming, the production of hay and grain, or to pasturage.

The territory east and north of Merced, the Plainsburg and Le Grand districts in the southeastern part of the county, much of the foothill area, and the greater part of the strip on the north side of Merced River are producing hay and grain, while the greater part of the area between the main line of the Southern Pacific Co. and San Joaquin River is in pasture. Part of this pasture land was at one time tilled, but for various reasons, among them the rise of alkali, tillage has ceased, and the lands have been returned to pasture. On the west side the strip above the canals and between them and the

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hills is generally in grain from Dos Palos northward. South of Dos Palos this strip is utilized principally as sheep range.

FLOWING WELLS.

The use of ground waters, like surface irrigation, is more usual in Merced than in Madera County, although it has not as yet become extensive in either county. The total number of flowing wells in the county is between 125 and 150. The greater number of these wells are shallow, from 100 to 400 feet deep, and their yield is correspondingly small. As the most of them were drilled twenty or twenty-five years ago, not for irrigation but for domestic purposes and for stock, they fulfill the function for which they were intended. Of the 130 or 135 flowing wells of which the Geological Survey has records, but 15 are reported as used for irrigation, and even these are generally used on a small alfalfa patch or garden of but little importance. The total yield of all the flowing wells in the county is estimated at less than 8 second-feet. That large yields may be secured is indicated by the experience of the Crocker-Huffman Land and Water Co. in sinking a 2,000-foot test well for oil in the spring of 1902 in sec. 15, T. 7 S., R. 13 E. No oil was found, but this well, although near the eastern edge of the flowing well area, as indicated by the shallow developments to date, yielded what is reported to have been the largest flow in the Merced district. When the casing was pulled the flow ceased, doubtless because of leakage into the upper strata. Practically all the flowing wells in the county are south and west of Merced and Livingston and east of Los Banos and South Dos Palos. Though there are many wells of this type 250 to 700 feet deep, they are principally for stock and domestic use, as the San Joaquin and Kings River canal system supplies plenty of cheap gravity water to this district.

PUMPING PLANTS.

There are between 40 and 50 pumping plants in the county, most of them equipped with gas engines. More than half of these are used to develop irrigating waters, and the remainder are used chiefly for domestic or town supplies. Grain, fruit, alfalfa, berries, sweet potatoes, etc., are the principal crops raised by the ranchers, who use pumping plants for irrigation. They express themselves as satisfied with the results and convinced that pump irrigation in many parts of Merced County may be made highly successful.

In the Atwater and Livingston districts, as well as about Plainsburg and Le Grand, plants have already proved practicable. Throughout much of the east side, to the west, south, and east of Merced, the ground-water level is within 20 feet or less of the surface, and where

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soils are favorable such accessible ground waters may be utilized to advantage in pumping operations.

Merced, like other east-side counties, includes a belt between the trough of the valley and the foothills that contains more or less alkali because of the proximity of the ground water to the surface. In certain parts of this belt the content of alkali has increased in recent years as the result of irrigation by means of gravity water supplied by the Crocker-Huffman system. In such areas, if the lands are still productive, pumping, either as an independent source of irrigation water or as an auxiliary to the gravity system, is most to be desired. It results in benefit to the community in several ways. In the first place it is a method of drainage. The water that is supplied to the land is drawn from beneath it. The tendency of the ground water to rise with irrigation is thereby counteracted and the ground water level is kept down. In the second place there is no overuse. Each acre-foot of water developed costs a fixed sum. Under these conditions more will not be used than is needed and the usual tendency of the ground-water plane to rise with irrigation will not be manifest. Again, pumping and the use of relatively high-priced water encourages intensive cultivation and this again reduces the quantity of water necessary. Frequent cultivation and the creation thereby of a mulch at the surface has long been recognized as one of the effective means of prevention of loss of water by evaporation from the surface. Whether lands already damaged by alkali as a result of the application of too much water can be reclaimed and utilized by pumping under the economic conditions that now exist is an unsettled question; but there is no doubt that the irrigation of undamaged lands whose water plane lies within 20 or 25 feet can be carried out successfully where intensive farming methods are used, and that the rise of alkalies in such lands will be prevented.

QUALITY OF WATER.

The east-side waters from wells 15 to 700 feet deep, ranging from 100 to 600 parts, average about 200 parts per million in their content of mineral matter. Though they differ considerably from each other in concentration those away from the trough are generally calcium carbonate waters good for irrigation and good to poor for boilers. Wells 100 to 1,000 feet deep in the territory indicated as lying east of line C′C′ on Plate II would probably yield water of the character just described. No apparent general difference in quality exists between the shallow waters and those down as far as 600 or 700 feet, though local differences of some magnitude are observable. For example, comparison of analyses (Tables 43 and 44) indicates that shallow waters at Merced are poorer than the deeper ones. Water

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Anna D. Ehlers	N. C.	20	...do	...do	Fair	Good.
Do	?	18	...do	$Ca-CO_3$	Poor	Fair.
J. F. Chamberlain	N. C.	17	...do	$Na-CO_3$	Fair	Do.
Miller & Lux	N. C.	50	...do	...do	...do	Good.
E. B. Fowler	?	80	...do	$Ca-CO_3$	...do	Do.
E. P. Tyler	N. C.	40	...do	...do	...do	Do.
August Tetzlaff	N. C.	35	Low	...do	...do	Do.
John Furtado	N. C.	12	Moderate	$Na-CO_3$	Good	Fair.
Do	N. C.	30	...do	$Ca-CO_3$	Fair	Good.
California Pastural & Agri[illegible]	N. C.	80	...do	...do	...do	Do.
W. Whelan	N. C.	140	...do	...do	...do	Do.
J. L. Gillette	N. C.	140	...do	...do	...do	Do.
T. B. Stribling	N. C.	100	...do	...do	...do	Do.
George D. Bliss	N. C.	80	...do	...do	...do	Do.
G. L. Hake	N. C.	80	...do	...do	...do	Do.

[illegible] C., [illegible]

[c] Three wells 172, 292, and 320 feet deep.

Owner.		Classification.				Analyst.
		Mineral content.	Chemical character.	Quality for boilers.	Quality for irrigation.	
A. J. Hulen	Oct.	Moderate	$Ca-CO_3$	Fair	Good	F. M. Eaton.
A. Erickson	Oct.	...do	$Na-CO_3$	...do	...do	Do.
Pacific Coast Oil Co.	May	High	$Na-SO_4$	Very bad	Fair	Pacific Coast Oil Co.
Do		...do	...do	...do	...do	Do.
Do	May	...do	...do	...do	Poor	Do.
Southern Pacific Co.	Aug.	Moderate	$Na-CO_3$	Fair	Good	Southern Pacific Co.
Miller & Lux	Oct.	High	Na-Cl	Very bad	Poor	F. M. Eaton.
John Kincaid	Oct.	...do	Ca-Cl	Bad	...do	Do.
California Pastural & Agricultural Co.	Oct.	Moderate	$Na-CO_3$	Good	Good	Do.
Miller & Lux		...do	...do	Fair	...do	Do.
Santa Fe Ry. Co.	Nov.	...do	Ca-CO	Poor	...do	Kennicott Water Softener Co.
Do		...do	...do	Fair	...do	Do.
Fresno Consumers Ice Co.	Jan.	High	...do	Bad	Fair	Smith, Emery & Co.
Do		Moderate	...do	Good	Good	Do.

[illegible]; second at 95 to 220 feet depth.

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from wells deeper than 700 feet could not be tested, but it is probable that borings more than 1,200 feet deep in the valley part of the county would yield salty or brackish water. It is reported that a 2,000-foot well in sec. 15, T. 7 S., R. 13 E., yielded soft water of fine quality, but it is probable that the water was strongly saline; no analyses of it are available, and the hole filled after removal of the casing.

Calcium carbonate waters are found along the east edge of the flowing-well area, but the supplies gradually become poorer toward the axis of the valley because of increasing predominance of the alkalies, so that many of those near San Joaquin River are poor to bad for irrigation. Artesian wells 300 to 600 feet deep in Tps. 6 S., R. 9 E.; 6 S., R. 10 E.; 7 S., R. 9 E.; 7 S., R. 10 E.; 7 S., R. 11 E.; and 8 S., R. 11 E., yield rather highly concentrated sodium chloride waters; several wells 250 to 700 feet deep southeast of those townships between Chowchilla Ranch and Merced, however, yield carbonate waters of good quality; consequently the sodium chloride waters may be considered to be confined to a belt near the axis and to be most common in the northern part of the belt. Wells 30 to 50 feet deep around the mouth of Merced River, where some of the strongest salt waters were found in deeper wells, yield good water.

Water from wells a few miles west of San Joaquin River contains appreciable amounts of sulphate, but that constituent is subordinate to carbonate in a strip extending from Newman into Los Banos Colony midway between the river and the foothills of the Coast Range. Though alkaline-earth bases are most commonly predominant, and the carbonate character of the water consequently does not spoil these waters for irrigation, they are poor for boiler use. Southeast of that area in Dos Palos Colony and the territory west of it the ground waters, being harder and higher in mineral content, are fair to poor for irrigation and bad for boiler use. The deep well at South Dos Palos yields salt water. The waters immediately northeast of Dos Palos Colony are somewhat better in quality.

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WELL RECORDS.

The records upon which the following tables were based were collected by W. N. White during the early summer of 1906 and by Messrs. A. J. Fiske, jr., R. M. Priest, and S. M. Smith during the preceding autumn. It is intended to summarize in them the essential facts about each well.

TABLE 45.—*Records of wells in Merced County.*

Owner.	Location.			Year completed.	Type and diameter of well.	Depth of well.	Depth to water level.	Temperature of water.	Method of lift.	Use of water.a	Yield.	Cost of well.	Cost of machinery.
	Section.	Township south.	Range east.										
						Feet.	*Feet.*	°*F.*			*Miner's inches.*		
Mary M. Harder	8	4	14	1877?	(*b*)	100	50	72	Wind	D, S			$70
Lucinda Fuller		4	14	1870?	Dug, 3 feet	63	59		do	D, S			
Mary M. Harder	17	4	14	1876?	Dug, 5 feet	50	46		do	S			50
San Francisco Savings Union	18	4	14	Old.	Dug, 3 feet	75	60		do	S			
Anderson school district	22	4	14	1890?	Dug, 4 feet by 4 feet	28	5.5		do	D			75
A. C. Barber	21	4	14	Old.	Dug, 4 feet	46	8½	65	Hand	D, S			
Mrs. C. Harder	30	4	14	1880?	do	58	53		Wind	D, S			
J. L. Allen	29	4	14	1903	Bored, 7 inches	106	94		do	D		$90	90
D. Wilson	33	4	14	1878	Dug, 5 feet by 5 feet	122	82.8		do	S			
D. A. Guernsey	27	4	14	1876?	Dug, 4 feet	58	42.4		do	S			90
Fred Spinker	31	4	14	1876?	Dug, 3 feet	97	91		do	D, S			
John Halverson	31	4	14	1881?	(*c*)	125	95		do	D, S			75
John Spenker	36	4	12	1890?	Dug, 5 feet	127	117.3		do	D, S			75
San Francisco Savings Union	35	4	13	1876?	do	71	55.8		do	D, S			60
Thomas Denigan	34	4	13	1865?	Bored, 7 feet	73?	54.6		do	S			
W. L. Dickenson	32	4	13	1883	Dug	150	140		do	D, S			
Caseretto estate	3	5	15	1859	Dug, 6 feet by 6 feet	27	18.3	70	Hand	D, S			
J. Ruddle	5	5	15	Old.	Dug, 3 feet	23	8		do	S			
H. G. Kelsey	5	5	15	1879	(*d*)	147			Wind	D		500	80
Sally Blake	7	5	15		Dug, 4 feet	60	40.7	70	Hand	D			
Sophia A. Irett	2	5	14	Old.	Bored, 7 inches		14		Wind	D, S			
Benjamin B. Robinson	11	5	14	1887?	do	60	27.4		do	D, S			
Eaton school district	15	5	14	1900	do	100	91		do	D			85
J. A. Robinson estate	16	5	14	1876?	Dug	134	124.2		do	D, S			65
William Youd	20	5	14	1883	Bored, 7 inches	150	120		do	D, S			
Blewett & Co	29	5	14	1886?	Bored, 9 inches	91	70		do	D, S			
George Youd	20	5	14	Old.	Bored, 7 inches	150	120		do	D, S			
H. K. Huls	17	5	14	1868?	do	150	24		Hand	D, S			

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J. P. Petersen	9	5	14	1901	Dug, 4 feet	18	12		Gas	D	e 10		
Snelling school district	4	5	14	1905	Dug	20	10		Hand	D			
Mrs. M. E. Bailey	4	5	14	1892?	Dug, 3 feet	18	11.9	65	....do	D			
D. H. Grubb	5	5	14	1883	Dug, 4 feet	127	99		Wind	D			90
A. Demichelli	8	5	14	1872?	Dug, 3 feet	11	8.7	65	Hand	D			
Arthur Dale	7	5	14	Old.		40	8	66	Wind	D			
J. R. McHenry	2	5	13	1888?	Bored, 7 inches	120	65		....do	D, S			
J. J. Stevinson	12	5	13	1886?	....do	110	88.4		....do				$100
W. J. Ferrell	13	5	13	1908	Dug, 4 feet by 4 feet	17	7.8	66	Hand	D, S			
Mrs. M. J. Little	23	5	13	1876?	Dug	60	8		....do	D, S			
J. G. Ruddle	14	5	13	1880?	Dug, 4 feet by 4 feet	26	9.2	66	....do	S			
Do	10	5	13	Old.	Dug, 3 feet	14	5		Wind	D, S			
C. O. Buckley	15	5	13	1860?	Dug	15	12		Hand	D, S			
Marie Grade	27	5	13	Old.	....do	10	6.5	62	....do	D			
H. Borland	28	5	13	1885?	....do	22	19		Wind	D, S			
Mrs. C. Ingalsbe	17	5	13	1886	Bored, 7 inches	100	50		....do	D, S			90
Ingalsbe estate	25	5	12	1900	....do	120	90		....do	D		$100	100
G. H. Barfield	25	5	12	1882	Dug	74	58		....do	D, S		60	60
R. Shaffer	36	5	12	1897	Bored, 7 inches	82	65		....do	D, S		250	
Fletcher Ryer	26	5	12	1881?	....do	90	83		....do	D, S			
I. M. Bailey	23	5	12	1880?	....do	120	116		....do	D, S			100
F. Ryer	22	5	12	1881	....do	120	90		....do	D, S			
C. H. Blodgett	16	5	12	1876?	....do	102	90		....do	D, S		90	
Thomas Goodwill	21	5	12	1882	....do	100	83.2		....do	D, S			90
R. Gracey	28	5	12	1886?	....do	120	84.1		....do	D, S			
Union Trust Co	27	5	12	Old.	....do	100	70.6		....do	D, S			
Hall Bros	33	5	12	Old.	....do	105	63.8		....do	D, S			65
M. M. Rouse, renter	25	5	11	Old.	....do	60	40		....do	S			
Olehan, Littlehill & Co	26	5	11	1905	(f)	52	32		Gas	N			
Do	26	5	11	1878?	Bored, 7 inches	75	32.4		Wind	S			
John Anderson	21	5	11	1878?	....do	55			....do	D, S			
C. F. Kinnercan	31	5	11	1891	....do	85	8.8		....do	D, S			
Carl J. Lunderen	30	5	11	1903	....do	84	6.4	68	....do	D, S			
C. J. Swanson	36	5	10	1903	....do	150	5.4	68	Hand	D			
Emil Hultman	36	5	10	1903	....do	78	6	70	....do	D, S			
	2	6	10	1876?	....do	25	2	66	....do	D, S			
Mr. Muller	3	6	10	Old.	....do	50?	7.8		Wind	D, S			
Joseph Marcks	3	6	10		....do	76	8		Hand	D, S			
A. Hallner	11	6	10	Old.	....do	33	4.5		Wind	D, S			65
	12	6	10	1886?	....do	58	10.5		Not raised	N			
August Erickson	10	6	10	1880?	....do	42	7.9		Wind	D, S			
George Oleson	8	6	10	1902	....do	60	6.5	68	....do	D, S		34	50
G. V. Nystrom	16	6	10	1903	....do	70	7	69	Hand	D, S			
E. G. Palmquist	14	6	10	1902	....do	38	5.3		....do	D		30	
John Anhstedt	15	6	10	1902	....do	80	7	69	Wind	D, S			70
Nels Shoreen	15	6	10	1904	....do	75	10	69	Hand	D		50	
C. A. Lundell	22	6	10	1886	....do	265?	0	72	Artesian	S	Small.		
Do	22	6	10	1903	....do	80	7.5	69	Hand	D		55	
Gus. Sward	27	6	10	3190	....do	40	10	69	....do	D			g 50

a D, domestic; S, stock; I, irrigation; B, boilers; N, not used.
b Dug 54 feet and bored 46 feet.
c Dug 95 feet and bored 30 feet.
d Dug 97 feet and bored 50 feet.
e Yield estimated or statement of owner taken.
f Dug 28 feet and bored 24 feet.
g Cost of well and equipment combined.

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TABLE 45.—*Records of wells in Merced County*—Continued.

Owner.	Location. Section.	Township south.	Range east.	Year completed.	Type and diameter of well.	Depth of well.	Depth to water level.	Temperature of water.	Method of lift.	Use of water.	Yield.	Cost of well.	Cost of machinery.
						Feet.	*Feet.*	°F.			*Miner's inches.*		
Mrs. H. Lundquest	27	6	10	1902	Hand	82	12	.....	Wind	D	.....	$65	$75
L. V. Estes	25	6	10	1902	....do	86	25	.....	....do	D, S	.....	.....	60
Chedester Sisters	36	6	10	1896	....do	66	20	.....	....do	D	.....	.....	50
J. A. Turner	34	6	10	1906	....do	70	11	.....	Hand	D	.....	58	.....
Albert Anderson	34	6	10	1903	....do	75	10.3	.....	....do	D	.....	50	.....
	33	6	10	1902	....do	40	10	69	....do	D	.....	.....	.....
Andrew Nohling	21	6	10	1903	....do	40	6.3	69	....do	D, S	.....	.....	.....
O. H. Miren	28	6	10	1880?	....do	83	7.8	.....	Wind	D	.....	.....	.....
A. Erickson	32	6	10	1902	....do	84	10	.....	....do	D	.....	70	.....
J. J. Stevinson	31	6	10	1870	....do	600?	0	70	Artesian	S	3	.....	.....
J. T. Tornquist	20	6	10	1903	....do	102	6	69	Hand	D	.....	75	.....
K. A. Peterson	19	6	10	1903	....do	33	8	69	Wind	D, S	.....	17	50
J. P. Snigg	18	6	10	Old.	Bored, 8 inches	350?	0	73	Artesian	N	.....	.....	.....
Peter Anderson	17	6	10	1902	Bored, 7 inches	36	8	68	Hand	D, S	.....	25	.....
California Alfalfa Colony Co	13	6	9	1883?	....do	.....	0	74	Artesian	S	a 1	.....	.....
Do	24	6	9	1884	....do	59	9.5	68	Hand	D, S	.....	.....	.....
John Robinson	22	6	9	1883?	....do	275	0	73	Artesian	S	a 4	.....	.....
Michel & Grossman	22	6	9	1885?	....do	275?	0	73	....do	D, S	a 4	.....	.....
C. M. Johnson	26	6	9	1894	....do	301	0	71	....do	D, S	a 2	.....	.....
M. Swensen	36	6	9	1904	....do	32	12	.....	Hand	D	.....	.....	.....
W. B. Beckwith	36	6	9	1886?	....do	300	0	.....	Artesian	D, S	a 2	.....	.....
J. Nichols	27	6	9	1883?	....do	300	0	72	....do	S	a 4	.....	.....
Michel & Grossman	26	6	9	1885?	....do	300	0	72	....do	S	a 3	.....	.....
Archie Turner	30	6	11	1886?	....do	69	29	.....	Hand	N	.....	.....	.....
Olcese & Garibaldi	29	6	11	1903	....do	68	32.5	.....	Wind	D, S	.....	.....	.....
M. B. Sears	29	6	11	1878	....do	46	30.2	.....	....do	D, S	.....	60	100
Olcese & Garibaldi	33	6	11	Old.	....do	62	32	.....	Hand	N	.....	.....	.....
J. J. Stevinson	28	6	11	1882?	....do	48	15.4	.....	Wind	D, S	.....	.....	.....
W. P. McConnell	27	6	11	Old.	....do	50	36.2	.....	....do	S	.....	.....	.....
Maussineo Aramajee	26	6	11	1906	Dug and bored	80	31	.....	Gas	I	.....	45	175
W. C. Blewett	26	6	11	1887	Bored, 7 inches	60	27	.....	Wind	D, S	.....	60	100
Hammett & Crowell	25	6	11	1904	(b)	72	31	.....	Gas	I	a 55	175	850
Do	26	6	11	1905	(c)	91	31	.....	....do	I	a 75	200	1,000
F. M. Ecclefield	23	6	11	1886?	Bored, 7 inches	65	32	.....	Wind	S	.....	.....	.....
Jos. Hitchcock	24	6	11	.....	....do	60	30	70	Hand	D, S	.....	.....	.....
W. P. McConnell	13	6	11	1903	....do	69	57	.....	Wind	D, S	.....	.....	110
	4	6	11	Old.	....do	74	14	.....	Not raised	N	.....	.....	.....

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N. R. Schmidt	4	6	12	1866?		50	25		Wind	D, S				
Santa Fe Ry. Co	99	6	12	1901?	Bored, 7 inches	100	60		Hand	D				
George Cressy	28	6	12	1881?	do	50	18		Wind	D, S				
Mrs. C. C. Crow	32	6	12	1876?	do		17		do	D, S				
W. H. Hartley	31	6	12		(d)	32	21		do	S				75
E. Gauthier	31	6	12	1876	Bored, 7 inches	78	20		do	D, S				
J. C. James	36	6	12	1903	do	42	26		Hand	D				e 50
Crocker Huffman Land & Water Co	26	6	12	Old.	do	24	21		Not raised	N				
A. G. McCoy	23	6	12	1906		65	43		Hand	D			42	
George Cressey	15	6	12	Old.		70	60		Wind	D, S				
J. S. Jones	11	6	12	1891	Bored, 8 inches	100	55	72	do	D, S			100	160
Amsterdam School district	9	6	13		Bored, 7 inches	108	66		do	D				
R. Schaeffer	20	6	13		do		22		do	D, S				
George Bloss	20	6	13		do	50	23		do	N				
W. C. Dallas	29	6	13		do	48	21		do	D, S				
L. A. Atwater	34	6	13	1880	(f)	100	33	72	do	D, S				
G. C. Jones	36	6	13		Bored, 6 inches	64	32		Wind and gas	D, S				175
B. Isenberg	19	6	14	Old.	Bored, 7 inches		75		Wind	D, S				
Mrs. Owens	20	6	14	1888	do	73	37.1		do	D, S				
D. S. Rosenbaum	18	6	14	1886	Bored	180	80		do	D, S				
Elmer Smith	21	6	14	Old.	Bored, 7 inches	200?	124.2		do	S				
McGann & Rector	30	6	14	Old.	do	112	28		do	D, S				90
John Schwinn	32	6	14	1890	do	60	30		do	D, S				
James Heggessy	32	6	14	1894	do	+100	50.5	73	do	D				50
Elmer Smith	35	6	14	1890	Bored, 8 inches	200	100	76	do	D, S				
A. Hill	2	7	14	1873	Bored, 7 inches	110	39		do	D, S				45
W. T. Nottingham	4	7	14	Old.	do	60	40		Hand	D				
E. P. Whitney	5	7	14	Old.	do	40	35.6		Wind	S				
Crocker Huffman Land & Water Co	6	7	14	1905	Dug, 4 feet	32	13		Electric	D, S, I	e 10			
E. M. Mills	8	7	14		Bored, 7 inches	34	9.6		Wind	D, S				55
A. L. Bartholomew	14	7	14	1885	Bored, 8 inches	60	18		do	D, S				
L. H. Applegate	7	7	15		Bored, 6 inches	65	20	70	do	N				
H. C. Wolfson	17	7	15	1897	do	40	20	69	do	D, S				
L. Coburn	16	7	15	1890	do	40	14	69	do	D, S				
S. Page	22	7	15		Bored, 7 inches	64	33	69	do	D, S				
G. H. Fancher	10	7	15		Bored, 6 inches	33	14		Not raised	N				
H. C. Wolfson	10	7	15		do	60	15	69	Wind	D, S				
Olcese & Garibaldi	14	7	15		do	70	30	69	do	D, S				
H. C. Wolfson	11	7	15		do	50	15		do	D, S				
Olcese & Garibaldi	12	7	15		do	65	29	68	do	D, S				
J. Cunningham	19	7	16	1894	do	30	8	70	do	S				
L. W. & J. M. Turner	29	7	16		do	25	10	70	do	S				
J. W. Mitchell estate	32	7	16		do	40	24		do	D, S				
D. Lewis	30	7	16		do	35	15	70	do	D, S				
M. Goldman	30	7	16		do	40	22		Hand	D, S				
J. Bean	25	7	15		do	+25	25	69	Wind	D, S				
Mrs. Reiley	36	7	15		do	42	23	70	do	D, S				
J. H. Pearl	27	7	15	1870	do	30	12		do	D, S				
Sophia E. Ivet	35	7	15		Bored, 7 inches	25	8.8		do	D, S				

a Yield estimated or statement of owner taken.
b Dug 30 feet and bored 42 feet.
c Dug 30 feet and bored 61 feet.
d Dug 14 feet and bored 18 feet.
e Cost of well and equipment combined.
f Two wells dug 50 feet and bored 50 feet, 7 inches in diameter.

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TABLE 45.—*Records of wells in Merced County*—Continued.

Owner.	Location.			Year completed.	Type and diameter of well.	Depth of well.	Depth to water level.	Temperature of water.	Method of lift.	Use of water.	Yield.	Cost of well.	Cost of machinery.
	Section.	Township south.	Range east.										
						Feet.	*Feet.*	°*F.*			*Miner's inches.*		
G. T. Farr	27	7	15	1904	Bored, 7 inches	32	14	68	Gas	D, S	[a] 2		
C. H. Fancher	28	7	15		Bored, 6 inches	30	16	69	Wind	D, S			
W. Whelan	32	7	15	1885	do	60	20	70	do	S			
E. Grimes	32	7	15	1890	do	58	21	70	do	D, S			
C. H. Fancher	29	7	15		do	30	23		Not raised	N			
D. Toal	31	7	15		do	65	22	70	Wind	D, S			
C. H. Fancher	30	7	15		Bored, 8 inches	75	20	69	do	D, S			
E. Grimes	24	7	14	1896	Bored, 6 inches	37	17	69	do	D, S			
G. H. Fancher	14	7	14	1905	Bored, 8 inches	30	12	68	Gas	D, S		$35	
W. H. Hartley	24	7	14	1890	Bored, 6 inches	38	17	68	Wind	D, S			
E. B. Fowler	36	7	14	1885	do	50	23	70	do	D, S			
E. Grimes	26	7	14		do	65	23	70	do	D, S			
R. B. Sheehy estate	33	7	14		Bored, 7 inches	35	8	71	do	D, S			
Do	31	7	14	1890?	do	81	4.8	68	do	D, S			
A. Bickford	30	7	14	1900	Bored, 6 inches	35	77		do	D, S		35	$85
George W. Ferris	20	7	14	1903	Bored, 7 inches	73	77		do	D, S		50	55
Santa Fe Ry. Co	19	7	14		Bored, 12 inches	56	14		Steam	B	[a] 22		
E. J. Olds	11	7	13	1875?	Bored, 7 inches		16		Wind	D, S			
Ed. Olds	3	7	13	1880	do	48	19		do	D, S			
A. J. Rodergues	5	7	13	1904	do	43	12	72	Hand	D, S		21	10
H. E. Reynolds	5	7	13	1903	do	67	18	72	do	D, S			
Jacob Feber	5	7	13	1904	do	65	13	72	do	D, S		30	7
Frank Gormen	8	7	13	1903	Bored	150	12	72	do	D, S		120	
P. Martinali	8	7	13	1904	Bored, 7 inches	35	8	72	do	D, S			
Joseph Calves	9	7	13	1903	do	41	8	72	do	D, S		20	
Frank Duart	9	7	13	1904	do	52	7	72	do	D, S			
Buhach P. & M. Co	8	7	13	1904	Bored, 12 inches	75	12	71	Gas	I	65		[b] 1,500
Do	8	7	13	1904	do	125			do	I			
Do.[c]	8	7	13	1895	do	87	12	71	do	I	[a] 75		[b] 1,500
L. F. Herrod	7	7	13	1893	Bored, 7 inches	44	11	71	Hand	D, S			
Frank Souza	17	7	13	1899	Bored, 6 inches	64	5	68	do	D, S		24	6
Joe Fratias	8	7	13	1900	Bored, 7 inches	22	6	71	do	S			
A. J. Freiens	9	7	13	1903	do	55	8	72	do	D, S			
M. C. Raymos	10	7	13	1903	do	37	8	72	do	D, S			
Jake Rogers	10	7	13	1901	do	24	8	72	do	D, S			
Thomas Hipp	12	7	13	1904	Bored, 4 inches	50	28	72	do	D, S			
J. Beck	14	7	13	1904	Bored, 7 inches	40	10		Wind	D, S		36	50

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Crocker Huffman Land & Water Co	14	7	13	.....	.....do	.....	14	66	.....do	D, S	.....	.....	.....	
Frank Freits	10	7	13	1904	Bored, 8 inches	54	9	.....	Hand	D, S	.....	.....	.....	50
Manuel Mancebo	15	7	13	1905	Bored, 7 inches	43	6	70	.....do	D, S	.....	.....	37	15
Banks & Peterson	16	7	13	.....	.....do	30	4	68	Wind	D, S	.....	.....	45	4
Frank Eduart	16	7	13	1902	Bored, 4 inches	38	3	68	Hand	D, S	.....	.....	30	50
Anton Frederico	17	7	13	1904	Bored, 12 inches	73	3	.....	Gas	I	.....	.....	15	4
Do	17	7	13	1904	.....do	53	.....	.....			.....	.....	.....	855
J. F. Weber	17	7	13	.....	Bored, 7 inches	45	6	66	Hand	D, S	.....	.....	.....	.....
Frank Novo	16	7	13	1903	.....do	32	7	66	.....do	D, S	.....	.....	20	4
C. J. Pregno	15	7	13	.....	.....do	59	4	68	.....do	D, S	.....	.....	.....	.....
Crocker Huffman Land & Water Co	15	7	13	1902	Bored, 12 to 6 inches	2,000?	3	.....	Not raised	N	.....	.....	.....	.....
P. Dupont	24	7	13	1889	Bored, 7 inches	35	8	.....	Wind	D, S	.....	.....	28	50
Southern Pacific Co	25	7	13	1873	Bored, 8 inches	500	3	.....	Not raised	N	.....	.....	.....	.....
A. E. Burnside	24	7	13	1893	Bored, 7 inches	85	6	68	Hand	D, S	.....	.....	.....	.....
John Reininghaus	23	7	13	1900	Bored, 8 inches	23	4	68	Wind	S	.....	.....	.....	50
Crocker estate	22	7	13	.....	Bored, 7 inches	41	4	.....	.....do	D, S	.....	.....	.....	75
J. B. Ivers	28	7	13	1899	.....do	78	7	67	Hand	D, S	.....	.....	.....	.....
H. A. Evellar	20	7	13	1899	.....do	43	8	68	.....do	D, S	.....	.....	20	4
H. F. Branco	20	7	13	1902	Bored, 8 inches	54	10	.....	Gas	I	.....	.....	.....	450
E. R. Vacheco	17	7	13	1904	Bored, 10 inches	95	16	.....	.....do	I	.....	.....	56	387
J. Pimentel	17	7	13	1898	Bored, 7 inches	40	8	.....	.....do	I	.....	.....	50	450
W. E. Mitchell	17	7	13	1901	.....do	50	5	67	Wind	D, S	.....	.....	30	.....
J. N. Davis	19	7	13	1904	Bored, 12 inches	45	7	.....	Gas	I	.....	.....	.....	600
W. A. Rucker	20	7	13	1900	Bored, 10 inches	59	6	.....	.....do	I	a 65	.....	41	530
Manuel Ventura	20	7	13	1904	.....do	67	8	.....	.....do	I	.....	.....	.....	300
J. N. Davis	19	7	13	1904	Bored, 12 inches	96	.....	.....	.....do	I	.....	.....	95	600
Do	19	7	13	1904	.....do	75	7	.....	.....do	I	.....	.....	.....	600
E. L. Stickney	24	7	12	1884	Bored, 7 inches	30	8	.....	Wind	D, S	.....	.....	35	100
Julia Moran	19	7	13	1904	Bored, 10 inches	72	8	.....	Gas	I	a 100	.....	59	500
Frank Frago	30	7	13	1891?	Bored, 7 inches	52	9	.....	Wind	D, S	.....	.....	.....	60
J. S. Balerio	20	7	13	1901	Bored, 8 inches	68	5	.....	Gas	I	.....	.....	60	700
R. E. Lee	29	7	13	1891?	Bored, 7 inches	47	4	72	Hand	D, S	.....	.....	.....	.....
P. Boland	30	7	13	1901	.....do	24	4	.....	.....do	S	.....	.....	13	.....
J. B. Ivers	21	7	13	.....	.....do	32	4	67	.....do	S	.....	.....	.....	.....
	27	7	13	.....	Bored, 12 inches	56	5	.....	Gas	I	.....	.....	.....	.....
J. G. Crowder	36	7	13	.....	Bored, 7 inches	34	4	68	Hand	D, S	.....	.....	.....	.....
Mrs. W. B. Turpen	26	7	13	1896	Bored, 6 inches	40	5	68	Wind	D, S	.....	.....	.....	.....
N. Freits	27	7	13	1890	Bored, 7 inches	30	10	68	Hand	D, S	.....	.....	.....	4
Peter Underveill	36	7	13	1901	.....do	19	4.9	67	Wind	D, S	.....	.....	.....	50
William Thornton	34	7	13	1885	Bored, 8 inches	33	7	68	Hand	D	.....	.....	10	4
William Hoffknecht	33	7	13	1895	Bored, 7 inches	45	5	68	.....do	D, S	.....	.....	22	4
Do	32	7	13	1903	Bored, 10 inches	46	7	.....	Gas	I	c 90	.....	40	700
Joseph Sullivan	33	7	13	1885	Bored, 7 inches	23	7	.....	Not raised	N	.....	.....	28	.....
	27	7	12	1904?	.....do	300?	0	72	Artesian	S	4	.....	.....	.....
J. M. Haile	26	7	12	1899?	.....do	55	9?	.....	Hand	D, S	.....	.....	.....	.....
L. H. Applegate	23	7	12	1890?	.....do	60	8	.....	Wind	S	.....	.....	.....	.....
J. S. Avila	12	7	12	1897	Bored, 6 inches	50	8	.....	Hand	D, S	.....	.....	.....	.....
J. B. Osborn	12	7	12	1890?	Bored, 7 inches	80	10	.....	Wind	D, S	.....	.....	.....	.....
Heber Foster	1	7	12	1891	Bored	70	20	72	.....do	D, S	.....	.....	.....	.....

a Yield estimated or statement of owner taken. b Cost of well and equipment combined. c Two wells.

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TABLE 45.—*Records of wells in Merced County*—Continued.

Owner.	Location.			Year completed.	Type and diameter of well.	Depth of well.	Depth to water level.	Temperature of water.	Method of lift.	Use of water.	Quantity of water.	Cost of well.	Cost of machinery.
	Section.	Township south.	Range east.										
						Feet.	*Feet.*	°*F.*			*Miner's inches.*		
W. B. Mitchell	1	6	12	.....	Bored, 7 inches	25	9	.....	Hand	D	.....	.....	.....
Manuel Mandonca	1	7	12	1902	Bored, 9 inches	50	12	71	Gas	I	.....	.....	[c] $460
Dell Dotto	1	7	12	.....	Bored, 7 inches	67	9	71	Hand	D	.....	.....	.....
W. H. Osborn	2	7	12	1895	....do	54	20	71	Wind	D, S	.....	$25	58
W. S. Crockett	2	7	12	1900	....do	57	8	71	Hand	D, S	.....	.....	.....
Martha Frager	11	7	12	1900	....do	54	8	70	....do	D, S	.....	.....	.....
Frank Goulart	11	7	12	1900	....do	65	8	71	....do	D, S	.....	35	8
E. Gauthier	5	7	12	Old.	....do	50	19	.....	Wind	D, S	.....	.....	.....
W. O. Robinson	7	7	12	Old.	....do	43	13	.....	....do	D, S	.....	.....	.....
Mitchell estate	22	7	12	1878	Bored, 9½ inches	.....	0	72	Artesian	S	[b] 1	.....	.....
W. C. Dallas	22	7	11	Old.	Bored, 7 inches	275?	0	73	....do	S	[b] 3	.....	.....
C. F. Blewett	2	7	11	1900?	Bored, 10 inches	60	19	.....	Gas	I	[b] 35	.....	[c] 1,000
Crane Bros	3	7	11	1881?	Bored, 7 inches	60	15	.....	Wind	D, S	.....	.....	.....
Mr. Webster	9	7	11	1902	....do	42	13	.....	....do	D, S	.....	.....	.....
G. S. Bloss, jr	9	7	11	1902?	....do	300?	0	73	Artesian	N	Small.	.....	.....
Do	16	7	11	Old.	....do	25	9.7	.....	Hand	D	.....	.....	.....
Crane Bros	22	7	11	1906	....do	250	0	72	Artesian	S	9	.....	.....
G. S. Bloss, jr	21	7	11	.....	....do	22	5	.....	Not raised	N	.....	.....	.....
Do	21	7	11	1905	....do	338	0	73	Artesian	D, S	7	.....	.....
Do	20	7	9	Old.	....do	10	4.5	.....	Not raised	N	.....	.....	.....
Do	33	7	11	1893?	Bored, 8 inches	328	0	73	Artesian	S	9	.....	.....
Crane Bros	3	8	11	1881?	Bored, 7 inches	300	0	73	....do	S	4	.....	.....
J. J. Stevinson	25	7	10	1870	....do	250	0	.....	....do	S	Small.	.....	.....
D. C. Van Cleef	13	7	10	.....	Bored, 1½ inches	14	4	.....	Hand	D	.....	.....	.....
J. J. Stevinson	11	7	10	1870	Bored, 7 inches	250	0	74	Artesian	N	[b] 2	.....	.....
S. W. Brannon	11	7	10	1898?	....do	17	4	62	Hand	D	.....	.....	.....
S. B. McCollough	14	7	10	1904	Bored, 1½ inches	14	6	.....	....do	D, S	.....	.....	.....
J. J. Stevinson	16	7	10	1903	Bored, 7 inches	256	0	73	Artesian	D, S	.....	.....	.....
Do	5	7	10	1870	....do	330	0	.....	....do	S	[b] 4	.....	.....
Do	7	7	10	1870	....do	330	0	74	....do	S	[b] 6	.....	.....
Do	6	7	10	1870	....do	330	0	73	....do	D	.....	.....	.....
Do	7	7	10	1870	....do	330	0	73	....do	S	Small.	.....	.....
J. J. Rhea	30	7	9	1898	....do	22	8	.....	Wind	D, S	.....	30	65
J. K. Boulware	30	7	9	1897	....do	160	8.8	.....	....do	D, S	.....	.....	45
Pacific Coast Oil Co.[c]	28	7	9	1902	Bored, 8 inches	180	3	.....	Steam	B	.....	.....	.....
P. Jeffson	32	7	9	.....	Bored, 1½ inches	22	6	71	Wind and hand	D, S	.....	.....	.....
Frank Munyan	36	7	9	1904	.....	52	12	.....	Wind	D, S	.....	45	45
Hubbard & Carmichael[c]	6	8	9	1892	Bored, 8 inches	42	17.5	.....	Steam and wind	D	.....	.....	.....

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F. B. Fentern	12	8	8	1901	Bored, 7 inches	25	11?		Wind	D, S				
R. H. Bambour	4	8	9	1896	Bored, 7 inches	120	4		do	D, S				
Bosesna & Steinberg	5	8	9	1888	Bored, 8 inches	500?	0		Artesian	D, S				
H. Sorensen	9	8	9	1905	Bored, 7 inches	60	4.2	66	Wind	D, S				
A. G. Worthington	9	8	9	1887?	Bored, 8 inches	580	0	77	Artesian	D, S			1,500?	
Simon Newman Co	12	8	8	Old.	Bored, 7 inches	+ 50	12		Wind	D, S				
Peter Bladt	14	8	8	1892	do	175	50?		do	D, S				
A. L. Hansen	14	8	8	1902	Bored, 8 inches	70	48.5		do	D, S			75	93
Simon Newman Co	15	8	8	1896?	Bored, 7 inches	125	20		do	D, S				
Major Eaches	22	8	8		do	125	70		do	D, S				
W. T. Bradley	28	8	8	1905	do	39	8		Hand					
E. L. Sturgeon	25	8	8		do	60	25	68	do	D, S				
William Bunker	20	8	9	1901	do	100?	9		Wind	D, S				
Woods estate	21	8	9		do	80	3		do	D, S				
B. F. Valliar	21	8	9	1896?	do	120	1		do	D, S				
Simon Newman Co	28	8	9	1887?	Bored, 10 inches	400?	0	77	Artesian	S	[b] 4			
H. T. Hauser	28	8	9	1906	Bored, 7 inches	111	4		Not installed					
J. L. Hale	29	8	9		Bored, 8 inches	196	10		Wind	D, S			375	122
M. L. Hunt	32	8	9	1895?	Bored, 8 inches	+300	1		Not raised	N				
Clarence Draper	31	8	9	1898?	Bored, 7 inches	173	15	71	Wind	D, S				
A. H. McBride	6	9	9	1902	do	21	13.1		Hand	D, S				
Charles Flick	32	8	9	1901	do	64	10		Gas	D, S				
H. T. Tilton	33	8	9	1890?	Bored, 8 inches	400	0	78	Artesian	S	[b] 2			
Simon Newman Co	3	9	9	1900	Bored, 7 inches	130	.7		Wind	N				
Do	11	9	9	1889?	Bored, 9½ inches	400?	0	78	Artesian	S	[c] 22		700	
Drummond & Page	9	9	9	1890?	Bored, 8 inches	430	0	77	do	S	Small.			
Ingomar school district	15	9	9		Bored, 7 inches	23	5.3		Hand	D	6			
P. Jorgensen	13	9	9	1891	Bored, 8 inches	402	0	78	Artesian	I			850	
Roger Fahy	27	9	9	1906	Bored, 8 inches	44	6		Wind	D, S				
Eugene McCabe	31	9	9	1905	Bored, 7 inches	60	12?		do	D, S				
John Barefles	1	10	9	1894	do	175	7?		do	D				
N. Bibby	31	9	10	1890	Dug, 3 feet	25	5		Hand	D, S				
C. W. Smith	32	9	10	1902	Bored, 7 inches	82	4		Wind	D, S				[a] 200
Pacific Coast Oil Co	36	9	10	1904	Bored, 10 to 7 inches.	750	0	79	Artesian	N	[b] 20			
Miller & Lux	12	10	10	1901	Bored, 7 inches	42	8		Wind	S				
Woods estate	8	10	10	1905	Bored, 6 inches	24	6		do	D, S			20	75
Miller & Lux	15	10	10		Bored, 1½ inches	15	8	62	Hand	D, S				
Woods estate	9	10	10	1906	Bored, 6 inches	45	6		Wind	D, S			40	
Southern Pacific Co	14	10	10	1888?	Bored, 8 inches	375	0?		Gas	B				
Miller & Lux	14	10	10	1891	do	325	0		Steam	D				
Do	23	10	10	1903	Bored, 7 inches	60	4?		Wind	D, S				
Benjamen Orognen	22	10	10		do	25	6		Wind and hand	D, S				
Miller & Lux	21	10	10	1895	do	40	3.4		Wind and horse	D				
M. Becker	19	10	10		Dug	12	8		Hand	D				
A. J. Hulen	24	10	9	1890	Bored, 7 inches	90	5		do	D, S				
H. F. Salau	19	10	10		do	30	8		Wind	D, S			45	60
A. H. Salau	29	10	10		do	21	7		Hand	D				
C. H. Waggoner	29	10	10	1870	Bored, 10 inches	50	11?		Wind	D, S				60
W. J. Jameson	21	10	10			80	7		do	D, S			80	35

[a] Cost of well and equipment combined.

[b] Yield estimated or statement of owner taken.

[c] Two wells.

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TABLE 45.—*Records of wells in Merced County*—Continued.

Owner.	Location. Section.	Township south.	Range east.	Year completed.	Type and diameter of well.	Depth of well.	Depth to water level.	Temperature of water.	Method of lift.	Use of water.	Yield.	Cost of well.	Cost of machinery.
						Feet.	*Feet.*	°*F.*			*Miner's inches.*		
J. L. Jameson	28	10	10	1899	Bored, 7 inches	30	8		Wind	D, S			
Emma Smith	27	10	10		Bored, 5 inches	30	5		do	D, S		$12	$35
C. P. Smith	23	10	10	1898	Bored	42	5?		do	D, S			a 100
Joe Waggoner	25	10	10	Old.	Bored, 6 inches	30	3		do	D, S			
W. M. Phillips	25	10	10	1898	do	25	10		do	D, S			a 200
George Blakeley	26	10	10		do	45	8		do	D, S			a 100
C. J. Welch[b]	35	10	10			39	8.2		Gas and wind	D		38	150
Mr. Chappel	34	10	10	1902	Bored, 7 inches	42	10		Wind	D, S			
George Waggoner	33	10	10	1866?	do	50	20		do	D, S			85
J. H. Wisenor	33	10	10	1856	Dug, 4 by 5 feet	50	33		Hand	S			
C. G. Acker	33	10	10	1876	Dug, 4 by 4 feet	50	30		Wind	D, S			a 150
G. D. Soper	5	11	10		Dug, 3 by 3 feet	80	13		Hand	D, S			
Miller & Lux	4	11	10	1894	Dug, 3 by 4 feet	60	52		do	S			
Do	3	11	10	Old.	Dug, 4 by 4 feet	28	22		do	D, S			
George Costen	11	11	10		Dug	20	12	66	Wind	D, S			
H. Hansen	12	11	10	1904	Dug, 3 by 3 feet	20	8	65	Hand	S			
Watkins Bros	11	11	10		Dug	180	45		Wind	D, S			35
G. J. Abeling	9	11	10		do	70	60		do	D, S			
U. G. Foat	31	11	10	1895	Bored, 7 inches		60		do	D, S			
J. L. Williams	15	11	10		Dug	86	78		do	D, S			65
J. O. Whiting	15	11	10	1905	Dug, 7 by 7 feet	83	70		Steam	I	55	175	1,000
W. T. Cheatham	23	11	10	1885?	Dug	80	60		Wind	D, S			
Alphonso	14	11	10		Bored, 7 inches		4		do	D, S			
S. E. Tulley	13	11	10		Dug, 4 by 5 feet	40	27		do	D, S			60
E. A. Scharnhorst	17	11	11		Dug	14	1.5		Hand	D, S			
Mr. Jameson	20	11	10		do	12	3		Wind	D, S			
Henry Miller	19	11	11	1900	Bored, 7 inches	45	13		do	D, S			
Do	19	11	11		Bored, 5 inches	300	5						
Do		11	10	1885?	Dug, 4 by 4 feet		80		Wind	S			
Miller & Lux	14	10	11	1905	Bored, 6 inches	372	0	+72	Artesian	D, S	2	700	
Do	13	10	11	1905	Bored, 5 inches	373	0	+72	do	S	3	700	
Do	13	10	11	Old.	Dug	60	12	69	Horse	D, S			
Do	16	10	12	1902	Bored, 6 inches	140	10?		Wind	D, S			
Henry Miller	Sanjon de Santa Rita.				Bored, 7 inches	130	8		do	D, S			
Do	do				do	350?	0		Artesian	S	Small.		
Do	do				do	350?	0	70	do	D, S	do		
Do	do				Bored, 8 inches	350	1		Horse	S			

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N. W. More	34	10	12	1905	Bored, 1½ inches?	20	12	66	Hand	D, S			
John Walder	33	10	12	1902	....do	15	9	64	....do	D, S			9
J. L. Vaught	34	10	12	1906	Bored, 5 inches	76	12	66	....do	D, S			
H. E. Goodwin	33	10	12	1906	Bored, 6 inches	72	10		Wind	D, S		56	
P. O. Baldwin	3	11	12	1902	Bored, 4 inches	78	10		....do	D, S			
J. A. Fisher	3	11	12	1905	Bored, 5 inches	42	7		....do	D, S		40	45
Miller & Lux	1	11	12			375	0		Artesian	D, S			
C. A. Bibler	10	11	12	1905	Bored, 6 inches	75	5		Wind	D, S		75	40
R. R. George	10	11	12		Bored, 1½ inches	23	8	67	Hand	D, S		10	
F. A. Bennett	11	11	12	1896	Bored, 5 inches	73	8		Wind	D		56	50
Joseph Walker	10	11	12		Bored, 1½ inches	20	6	65	Hand	D, S			
H. J. Quivey	15	11	12	1903	....do	17	5	63	....do	D, S			
E. Sorg	14	11	12		Dug, 3 by 3 feet	20	9	62	....do	D, S			
Miller & Lux	21	11	12	Old.	Bored, 8 inches	550	0	76	Artesian	S	Small.		
Do	22	11	12	1891	....do	550	0	76	....do	S	2		
G. H. Drakley	4	8	12	1876?	Bored, 7 inches	270	0	72	....do	I, S	c 3	300	
O. B. Randall	4	8	12	1881?	....do	240	0		....do	I	10	250	
Mrs. F. E. Turner	4	8	12	1877?	....do	270	0	72	....do	D, S	5	325	
School district	3	8	12	Old.	....do	35	6.7		Wind	D			
J. T. Lander	3	8	12	1877	....do	206	0		Artesian	I	c 3	250	
J. J. Sanders	2	8	12	1879	....do	275	0	73	....do	D, S	c 2	300	
Do	10	8	12	1879	....do	275	0	73	....do	D, S	c 4	300	
John Lander	4	8	12	1896?	....do	275?	0	72	....do	D, S	6		
Mrs. F. E. Turner	4	8	12	Old.	....do		0	73	....do	S	1		
J. J. Sanders	9	8	12	1877	....do	285?	0	72	....do	D, S	3		
Do	10	8	12	1879	....do	297	0	73	....do	D, S	c 2		
Do	15	8	12	1878	....do	260	0	73	....do	D, S	c 1		
Do	15	8	12	1879	....do	250	0	74	....do	S	6		
William Sharon estate	24	8	12	Old.	....do	200	0	74	....do	S	c 1		
Miller & Lux	36	8	12		....do		0	74	....do	S	6		
Mrs. Croop	32	8	13	1896	....do	300?	0	74	....do	S	Small.	300	
Stockton Savings Association	30	8	13	1888?	....do	300?	0		....do	D, S			
O. E. Gribi	20	8	13	1883	....do	200	0	73	....do	D, S	c 1	250	
William A. Saunders	19	8	13	Old.	....do	200?	0		....do	S	Small.		
C. H. Dean	6	8	13		Bored	60	9	68	Wind	D, S			
John Pilger	4	8	13		Bored, 8 inches	60	5	67	Hand	D, S			
Mr. Johnson	4	8	13		Bored, 7 inches	42	5	65	....do	D, S			
Mr. Mitchell	3	8	13		....do	37	5	67	....do	D, S			
Crocker Huffman Land & Water Co	3	8	13	1890?	Bored, 8 inches	685	0	76	Artesian	S	3		
W. H. Hartley	1	8	13	1904	....do	275	0	76	....do	D, S, I	c 2	300	
Crocker Huffman Land & Water Co	9	8	13	1905	....do	250?	0	75	....do	D, S, I	4		
John Roduner	16	8	13	1894?	Bored, 9 inches	707	0	75	....do	I	7		
Do	16	8	13	Old.	Bored, 8 inches	250?	0	74	....do	S	Small.		
S. M. Pate	21	8	13	1903	Bored, 12 inches	96	11		Gas	I	c 90	100	1,100
Do	21	8	13	1882	Bored, 7 inches	146	0	73	Artesian	D, S	Small.		
Crocker estate	24	8	13	1886?	....do	151	0	74	....do	S	Small.		
School district	24	8	13		....do	35	7	70	Hand	D			
M. Rahilly	23	8	13	1886?	....do	160	0	72	Artesian	S	c2		
Do	26	8	13	1887?	Bored, 9½ inches	750	0	74	....do	S		1,100	

a Cost of well and equipment combined.

b Two wells.

Yield estimated or statement of owner taken.

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TABLE 45.—*Records of wells in Merced County*—Continued.

Owner.	Location. Section.	Township south.	Range east.	Year completed.	Type and diameter of well.	Depth of well.	Depth to water level.	Temperature of water.	Method of lift.	Use of water.	Yield.	Cost of well.	Cost of machinery.
						Feet.	*Feet.*	°*F.*			*Miner's inches.*		
M. Rahilly	27	8	13	1890?	Bored, 7 inches	280	0	72	Artesian	D, S	Small.		
Do	26	8	13			135	0		do	N	a 2		
Williams Collins	25	8	13	1885?	Bored, 7 inches	149	0	72	do	D, S, I	a 2		
Mrs. E. H. Brouse				1890?	do	228	0		do	D, S			
Patrick McNamara	19	8	14	1906	do	109	0		do	D, S	a 2		
Do	20	8	14	1873?	do	116	1.5	73		S	Small.		
Do	19	8	14	1880?	do	120	0	74	Artesian	S	Small.		
M. Rahilly	18	8	14	1886?	do	175	0	74	do	D, S		$199	
George Minges	7	8	14	1905	do	170	0	74	do	S	Small.	200	
Do	7	8	14	1905	Bored, 10 inches	117	10		Gas	I			
Pacific Improvement Co	4	8	14	Old.	Bored, 7 inches	30	4		Wind	D, S			
Do	3	8	14		Bored, 6 inches	45	10	71	do	D, S			
E. F. Mugler	12	9	14		do	50	12	71	do	D			
William Campbell	11	8	14		Bored, 12 inches	90	12		Gas	I		23	$500
E. T. Givens	14	8	14		do	200	13		do	I			
Olcese & Croop	9	8	14	1903	Bored, 7 inches	60	4.5		Wind	S			65
James C. Chamberlain	16	8	14	Old.	Bored	40	4	68	do	D, S			
August Tetzlaff	27	8	14	1881?	Bored, 7 inches	325	0	74	Artesian	D, S	a 1	375	
Do	27	8	14	1906	Bored, 8 inches	344	0	74	do	S	a 2	500	
Do	28	8	14		Bored, 7 inches	30	4		Wind	N			
W. A. Aldrich	25	8	14	1896	do	90	0		do	D, S			
P. Carroll estate	6	8	15		Bored, 6 inches	44	17	70	do	S			
P. Sheehy estate	5	8	15		do	58	18	70	do	D, S			
Mrs. L. P. Twichell	3	8	15		Bored, 7 inches	30	12	70	do	S			
M. C. Burchell	1	8	15	Old.					do	D, S			
Do	1	8	15		Bored, 7 inches	8	4.5		Not raised	N			
R. M. Burchell	11	8	15	1897?	do	60?	12		Wind	D			85
S. L. Ritchie [b]	13	8	15	1905	Bored, 10 inches	275	18		Gas	I		600	725
J. Vetterly	13	8	15	1906	do	200	16.5						
Do	13	8	15	1900	Bored, 7 inches	160	20		Wind	D, S			
M. A. Poor	10	8	15	1893	Bored, 6 inches	32	14	71	do	D, S			
E. D. Kahl	9	8	15		do	35	15		do	D, S			
A. S. Kahl	9	8	15		do	+30	+14	70	do	D, S			
A. W. Moreley	8	8	15		Bored, 7 inches	40	16	71	do	D, S			
L. M. Helmer	7	8	15		do	30	13	71	do	D, S			
Mrs. L. P. Twitchell	7	8	15		Bored, 6 inches	28	15		do	D, S			
Joseph Vasche	18	8	15	1899	Bored, 7 inches	30	12		do	D, S			90
Do	20	8	15	1888	do	30	6?	68	do	D, S		30	90
George L. Vetterly	20	8	15	1904	do	65	8		do	D, S		70	90

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J. M. Cunningham	21	8	15	1901	do	60	8		do	D, S			75
S. Hein	16	8	15	1881?	Bored, 6 inches	75	11	68	do	D, S			
E. L. Morley	15	8	15	1886?	Bored, 7 inches	100	9		do	D, S			
Lee Fancher	23	8	15	Old.	do	40	10		do	D, S			
J. L. Gillette	24	8	15	1892	do	18	13		do	D, S		20	80
Paul Newman	13	8	15	1876?	do	60	13		do	D, S			
Do	24	8	15	Old.	do	22	10		do	D, S			
T. B. Stribling	29	8	15	1880	do	75	9		do	D, S		100	90
E. D. Hollister	29	8	15	1879	do	60	8		do	D, S			120
Mrs. Fischer	31	8	15	Old.	do	55	5		do	S			
M. M. Ritchey	35	8	15	1890	do	49	16		do	D, S			
Do	35	8	15		do	50?	12		do	S			50
C. C. Clausen	35	8	15	1884	do	39	13.9		do	D, S			
E. W. Harrison	31	8	16	Old.	do	32	12.8		do	S			65
N. O. Miller	30	8	16	1891	do	33	11		do	D, S			55
Paul Newman	19	8	16	1890?	do	100	10.2		do	S			
G. L. Hake	19	8	16	1902	do	100	16.5		do	I		90	125
Santa Fe Ry. Co	17	8	16	1898	Bored, 10 inches	198	12		Steam	B	9		
J. S. Mitchell	16	8	16	1902	Bored, 7 inches	150	12		Wind	D, S		85	70
I. Diffin	16	8	16	1900	Bored	50	12	65	do	S		45	
W. Wolsey	10	8	16	1896	Bored, 7 inches		12?		do	D, S			
R. H. Wallis	11	8	16	1888	Dug	15	12.5		do	D, S			65
John Baker	11	8	16		Bored, 7 inches	40	17	70	do	D, S			40
C. A. Phenegar	24	8	16	1902	do	54	8		do	D, S			75
J. W. Stevens estate	23	8	16	1902?	do	120	16?		do	D, S			75
A. J. Martin	15	8	16	1904	do	160	16	70	do	D, I		85	
G. L. Gillette	21	8	16	1895	do		12?		do	D, I			
Ah See	20	8	16		Bored, 10 inches	90	12		Gas	I	[a]10		
J. F. Jones	20	8	16	1903	Bored, 7 inches	90							
Do				1903	do	120	12		Steam	N			
G. L. Hake	19	8	16	1898	do	24	13.5		Wind	D, S			40
Jacob Ipsen	20	8	16		do	22	14	69	do	D, S			[c]110
D. W. Eno	28	8	16	1903	Dug, 30 inches	24	16.8	69	do	D, S			60
R. Earl	29	8	16	1884	Bored, 7 inches	30	11.2		do	D, S		25	70
E. W. Harrison	31	8	16		Dug, 3 feet	17	13.5		Hand	S			
C. Dooley	33	8	16	Old.	Bored, 7 inches	30	12.3		Not raised	N			
A. A. Hansen	27	8	16	1903	do	57	21		Wind	D, S, I		12	50
Joe King	27	8	16		do	70?	30		do	D, S			85
Mr. Underwood	36	8	16	Old.	do	80	25		do	N			
C. A. Phenegar	18	8	17	1904	do	184	15		do	S		156	50
Adam Schinn estate	20	8	17	1906	do	140	3?		do	S		75	
Do	21	8	17	1846	Dug, 3 feet	10	7.2		do	D, S			45
J. J. Jones	34	8	17	1858?	Dug	67	14		do	D, S			57
Mrs. J. Murdock	28	8	17	Old.	Bored, 7 inches	76	35.5		do	D, S			45
J. Baxter	32	8	17	1899	do	75	40		do	S			
James Kern	4	9	16	Old.	do	50?	30		Wind and horse	D, S			40
Jonathan Fancher	2	9	15	1886	do	100	14		Wind	D, S			45
M. A. McCloskey	3	9	15	1891	do	56	10.5		do	D, S		42	45
Hayes & Co	5	9	15	1881	do	75	6		do	D, S			

[a] Yield estimated or statement of owner taken.

[b] Two wells.

[c] Cost of well and equipment combined.

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TABLE 45.—*Records of wells in Merced County*—Continued.

Owner.	Location. Section.	Township south.	Range east.	Year completed.	Type and diameter of well.	Depth of well.	Depth to water level.	Temperature of water.	Method of lift.	Use of water.	Yield.	Cost of well.	Cost of machinery.
						Feet.	*Feet.*	°*F.*			*Miner's inches.*		
Bliss Bros.	29	8	15	1875?	Bored, 12 inches	350	0	72	Artesian	S	a 4		
Do.	30	8	15	1880	Bored, 8 inches	350	0	71	do	S	a 2		
F. L. Frietes	2	9	14		Bored, 7 inches	50	10	69	Hand	S		350	
Do.	3	9	14	1904	do	191	0	74	Artesian	D, S	Small.	250	
Mr. Lord	4	9	14	Old.	do		0	74	do	S	a 1		
John Furtado	8	9	14	Old.	Bored, 8 inches	250?	0	74	do	S	a 2		
Lillie Brouse	5	9	14	Old.	Bored, 7 inches		0		do	S	a 1		
John Furtado	7	9	14	1896?	do	250?	0	74	do	S	a 1		
Do.	7	9	14	1903	do	60	6.6	68	Wind	D			
California Pastural & Agricultural Co.	20	9	14		do		0	72	Artesian	S	Small.		
Bliss Bros.	23	9	14	1875	do	250	0	72	do	S	a 3		
Do.	26	9	14	1875?	Bored, 8 inches	350?	0		do	S			
Do.	28	9	14	1875?	do	275	0		do	S	Small.		
California Pastural & Agricultural Co.	20	9	14	1900	Bored, 7 inches	273	0		do	S	2		
Do.	5	10	14	Old.	Bored, 6 inches	155	0	68	do	S			
Do.	6	10	14	Old.	do	283	0	70	do	D, S	1		
Jose Frietes	1	9	13	1903	Bored, 7 inches	207	0		do	I	a 2		
Do.	1	9	13	1871	do	225	0	74	do	I	Small.		
T. S. Howell	1	9	13	1878?	do	300?	0	74	do	D, S	1		
Mr. McNell	2	9	13		Dug	16	9		Wind	D, S			
L. H. Silman	2	9	13	1876?	Bored, 7 inches	230	0	73	Artesian	I	Small.	300	
Mr. Rogers	11	9	13	1881	do	150	0	74	do	S	Small.		
Anna Silman	10	9	13	1886?	do	230	0	74	do	S	Small.		
Bowman & McGarr	3	9	13	1903	do	230	0		do	S	a 3		
Silas Bowman	4	9	13	1896	do	320	0	74	do	S	a 1		
M. E. Wasson	4	9	13	1892	do	292	0	74	do	I	a 1		
Silas Bowman	4	9	13	1894	Bored, 9 inches	698	0	73	do	S, I	12		
L. L. Wolfsen	5	9	13	1884	Bored, 7 inches	300	0	74	do	S	5		
Miller & Lux	2	9	12	Old.	Bored, 6 inches	32	8.7		Not raised	N			
Do.	2	9	12		do		0	74	Artesian	S	15		
Do.	12	9	12	Old.	Bored, 7 inches		0		do	S			
Mrs. K. Kocher	7	9	13	1885?	do	290	0	74	do	S	3	300	
L. L. Wolfsen	6	9	13	1881	do	295	0	73	do	S	3		
Mrs. S. Croop	6	9	13	1888	do	315	0	75	do	I	3	350	
W. H. Hurd	8	9	13	1893?	do	277	0	73	do	I	7		
Silas Bowman	5	9	13	1892	do	310	0	73	do	S	Small.		
Miller & Lux	13	9	13	Old.	do		0	74	do	S			
M. Rahilly	14	9	13	1885?	do	230	0	73	do	S	a 1	250	

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Mrs. C. Desmarais	13	9	13	1876?	....do	315	0	73	....do	D, S	Small.		
Do	13	9	13	1875	....do	375	0	73	....do	S	a 1		
Do	23	9	13	1875?	....do	300?	0	73	....do	S	a 1		
J. T. Flanagan	24	9	13	1886?	....do	160	0	71	....do	D, S	Small.		
Do	24	9	13	1886?	Bored, 10 inches	1,000?	0	77	....do	S, I	16	1,500	
Do	23	9	13	1886?	Bored	250?	0	72	....do	I	Small.		
H. H. Hall	23	9	13	1893	Bored, 7 inches	297	0		....do	D, S	Small.		
Do	23	9	13	1881?	....do	275?	0		....do	D, S	Small.		
Anna D. Ehlers	15	9	13	1887	....do	300	0		....do	D, S, I	Small.	300	
Do	15	9	13	1889?	....do	70	8.3		Hand	D			
Do	13	9	13	1887	....do	300	0	74	Artesian	D, S, I	Small.	300	
Do	15	9	13	1887	....do	300	0	74	....do	S	Small.	300	
James F. Chamberlain	21	9	13	1880?	....do	350	0	74	Artesian	S	6	$300	
Do	29	9	13		Bored, 1½ inches	20	7	69	Hand	S			
Do	21	9	13	1880?	Bored, 9½ inches	400	0	74	Artesian	S, I	a 4		
Do	21	9	13	1875	Bored, 7 inches	350	0	74	....do	S, I	a 2		
Do	28	9	13	1883?	....do	360?	0	73	....do	S	4		
Do	21	9	13	1880?	....do	340	0	74	....do	S		300	
Do	22	9	13	1883?	....do	360?	0	74	....do	S	a 2		
Walter Hickman	27	9	13	1905	Dug	29	10.8		Gas	I	50		
Do	26	9	13	1880?	Bored, 7 inches	300	0	73	Artesian	D, I	a 1		
California Pastural & Agricultural Co	25	9	13	Old.	....do		0	73	....do	S	a 2		
Do	25	9	13	Old.	Bored, 6 inches		0	72	....do	S	Small.		
Do	1	10	13	1904	Bored, 7 inches	270	0		....do	S	a 4		

a Yield estimated or statement of owner taken.

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MADERA COUNTY.

GENERAL CONDITIONS.

The valley portion of Madera County is limited on the south and west by San Joaquin River and on the north by the Chowchilla. Irrigation by surface water is practiced about Madera through the utilization of Fresno River water in the early summer, when it is available, and about Minturn, near the north edge of the county, by the similar use of Chowchilla River water. Both of these streams have small mountain drainage basins, so that the flow from them is not prolonged late into the summer.

The extreme western edge of the county is also under irrigation from gravity water. The Chowchilla canal heads on the north side of the San Joaquin, about 6 miles east of Mendota, and runs northward, generally parallel to the river, for about 20 miles, commanding a strip 5 or 6 miles wide between it and the river. The greater part of the rest of the county is as yet grain land or pasture land, intensive cultivation being practiced only locally, extensive holdings near the river being given over to stock ranches.

FLOWING WELLS.

The ground waters have not been drawn upon to any extent for irrigation in the developments that have taken place thus far. There are about 30 flowing wells in the 350 square miles of artesian water-bearing land in the county, and these are practically all used for watering stock on the Chowchilla ranch and the Bliss and Miller & Lux properties. The total yield for all of the flowing wells is estimated to be less than 8 cubic feet per second, although at least one of the individual wells yields more than 1 cubic foot per second. These wells are generally shallow, depths of 200 to 400 feet being usual. Some of them are among the oldest in California, having been drilled nearly 40 years ago, and though there has been some lessening in yield it is doubtless due to deterioration of the casing and to clogging. A table of measurements made at different periods is appended:

TABLE 46.— *Yield of flowing wells in Madera County.*

Location.	Yield in miner's inches.		
	1871	1884	1905
Sec. 21, T. 10 S., R. 14 E	20	13	10
Sec. 4, T. 10 S., R. 15 E	22	18	11
Sec. 25, T. 10 S., R. 15 E	4	6	.....
Sec. 16, T. 10 S., R. 14 E	1.1	3	12
Sec. 23, T. 10 S., R. 13 E	.....	5	2
Sec. 14, T. 10 S., R. 13 E	.....	23	12

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The well in sec. 16, T. 10 S., R. 14 E., was recently cleaned and responded with a stronger flow than it had ever yielded before. The fact of a well-maintained pressure and supply is further indicated by the strong flows of new wells put down in the vicinity of older ones, tapping the same water-bearing beds.

It is evident that these cheap waters can be developed in large volume in the western part of Madera County if it is desired.

PUMPING PLANTS.

About 15 pumping plants in the county were in use for irrigation in 1906. Most of these are in the vicinity of Borden, where the ground-water level lies at a depth of from 10 to 20 feet. The pumps pull the water level down locally 15 or 20 feet, so that the total lift is usually 25 to 40 feet. Irrigators estimate that under these conditions they can deliver water for about 75 cents per acre-foot for fuel and labor. Even lower figures are given for the best-equipped plants.

Interest on investment and deterioration of plant, of course, increase this cost somewhat, yet it is certainly well within the limits of profitable use. Practically everywhere within that part of the county west of the Southern Pacific, except near the bluffs of San Joaquin River, pumping waters are accessible. As the foothills are approached, depth to ground water increases and the lift necessary in their development increases correspondingly.

QUALITY OF WATER.

The waters that were tested in Madera County away from the axis of the valley are similar to those in the east part of Merced County. Wells 20 to 400 feet deep yield water good for irrigation and fair to poor for boiler use. The supplies are low in alkali and moderate in scale-forming constituents, and wells probably could be bored to 1,000 feet without striking poorer water. The quality of the water from the 1,310-foot well in sec. 32, T. 11 S., R. 18 E., indicates that the very deep supplies are salty and therefore unfit for use.

Flowing wells 240 to 400 feet deep on the Chowchilla and Bliss ranches in the northwest part of the county near San Joaquin River yield supplies perfectly acceptable for irrigation, and another in sec. 34, T. 11 S., R. 16 E., probably between 300 and 500 feet deep, yields good water; artesian waters between the 300 and 500 foot depths and 9 miles or more from the river are probably satisfactory. But the water from the 520-foot well at Berendo Sheds in sec. 6, T. 13 S., R. 15 E., is strongly saline and unfit for use either in boilers or for irrigation. An artesian water from a well of nearly the same depth at Miller pumping station, 4 miles farther west (analysis, Table

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51, p. 238), is higher in sulphate but much lower in chloride. A plugged 96-foot well at the latter place is said to have yielded salt water. The 437-foot well in sec. 33, T. 11 S., R. 13 E. (analysis, Table 50, p. 238), also yields salt water. These data, with those regarding artesian supplies around South Dos Palos, indicate that flowing wells near San Joaquin River are likely to strike salt water between 400 and 600 feet, and there is no good reason for believing that deeper supplies would be any better.

Tables 47 and 48 give the analyses and assays of the ground waters of Madera County that have been examined.

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Owner.	Alkali coefficient (k) (inches).	Classification. Mineral content.	Chemical character.	Quality for boilers.	Quality for irrigation.
Geo. D. Bliss	100	Moderate..	$Ca\text{-}CO_3$...	Fair.....	Good.
Do	70	...do.....	...do.....	...do.....	Do.
Do	70	...do.....	...do.....	...do.....	Do.
Miller & Lux	14	...do.....	$Na\text{-}CO_3$...	...do.....	Fair.
Do	1.2	Very high.	Na-Cl.....	Very bad .	Bad.
Do	80	Moderate..	$Ca\text{-}CO_3$...	Fair.....	Good.
Sharon estate	70	...do.....	...do.....	...do.....	Do.
Mrs. Casey	50	...do.....	...do.....	...do.....	Do.
Miller & Lux	50	...do.....	...do.....	...do.....	Do.
Do	140	...do.....	...do.....	...do.....	Do.
Sharon estate	25	...do.....	...do.....	...do.....	Do.
Thomas Moulding	19	...do.....	...do.....	Poor.....	Do.
H. W. Thomas	45	...do.....	...do.....	...do.....	Do.
Sharon estate	80	...do.....	...do.....	Fair.....	Do.
Pope & Talbot	55	...do.....	...do.....	...do.....	Do.
A. L. Sayre	1.8	High.....	Na-Cl.....	Very bad .	Bad.
Do	25	Moderate..	$Na\text{-}CO_3$...	Fair.....	Good.
S. Y. Cockrum	140	...do.....	$Ca\text{-}CO_3$...	...do.....	Do.
S. Shepherd					

pably more than 300 feet.

Owner.	Da	Classification. Chemical character.	Quality for boilers.	Quality for irrigation.	Analyst.
Geo. D. Bliss	Oct. 1	$Ca\text{-}CO_3$....	Fair.....	Good....	F. M. Eaton.
Sierra Vista Vineyard Co.	.....do	...do.....	Good.....	...do.....	Do.
Southern Pacific Co	May,	...do.....	Fair.....	...do.....	Southern Pacific Co.
Atchison, Topeka & Santa Fe Railway Co.	Oct.	$Na\text{-}CO_3$....	...do.....	...do.....	Kennicott Water Softener Co.

oxides of iron and aluminum.

s C.,

98205°—wsp 398—16.

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The essential facts secured as to the most important wells in Madera County examined by Messrs. A. J. Fiske, jr., R. M. Priest, and S. M. Smith in 1905–6 have been assembled in the accompanying table.

TABLE 49.—*Records of wells in Madera County.*

Owner.	Location. Section.	Township south.	Range east.	Year completed.	Type and diameter of well.	Depth of well.	Depth to water level.	Temperature of water.	Method of lift.	Use of water.[a]	Quantity of water.	Cost of well.	Cost of machinery.
						Feet.	*Feet.*	°*F.*			*Miner's inches.*		
W. D. Cardwell	28	9	16	.....	Bored, 7 inches	54	22	66	Horse	D, S	.....	.....	.....
Sharon estate	30	9	17	.....	Bored, 8 inches	72	48	.....	do	N	.....	.....	.....
Do	28	9	17	.....	do	100	65	67	Wind	N	.....	.....	.....
Do	23	9	17	.....	do	85	57	.....	Horse	S	.....	.....	.....
Do	19	9	18	.....	do	100	50	.....	Wind	N	.....	.....	.....
J. F. Daulton	20	9	18	.....	do	60	30	60	Horse	D, S	.....	.....	.....
Sharon estate	28	9	18	.....	do	100	72	.....	do	N	.....	.....	.....
J. F. Daulton	29	9	18	.....	do	26	26	68	Wind	D, S	.....	.....	.....
Pope & Talbot	8	10	18	.....	do	+125	+100	65	do	D, S	.....	.....	.....
Sharon estate	1	10	17	.....	do	100	50	.....	Horse	N	.....	.....	.....
Do	11	10	11	.....	do	75	46	.....	Wind	N	.....	.....	.....
Do	5	10	17	.....	do	110	50	67	do	S	.....	.....	.....
H. H. Stark	8	10	17	.....	do	60	37	67	do	D, S	.....	.....	.....
McCabe Bros	2	10	16	.....	Bored, 6 inches	40	22	66	do	D, S	.....	.....	.....
Sharon estate	11	10	16	.....	Bored, 8 inches	46	21	.....	Horse	N	.....	.....	.....
Do	10	10	16	.....	Bored, 7 inches	52	21	65	Wind	S	.....	.....	.....
Do	15	10	16	.....	do	47	20	.....	Horse	D, S	.....	.....	.....
Mr. Hemmel	9	10	16	.....	Bored, 6 inches	65	22	.....	do	D, S	.....	.....	.....
C. H. Brown	5	10	16	1890	do	40	23	67	Wind	D, S	.....	.....	.....
O. W. Garlinghouse	33	9	16	.....	Bored, 8 inches	48	24	.....	do	D, S	.....	.....	.....
California Pastural & Agricultural Co	4	10	15	.....	Bored, 7 inches	.....	0	72	Artesian	S	4	.....	.....
Do	5	10	15	1887	do	212	0	70	do	S	[b] 3	.....	.....
Do	8	10	15	.....	do	.....	0	.....	do	S	.....	.....	.....
Do	16	10	15	.....	Bored, 8 inches	.....	0	70	do	S	Small	.....	.....
Do	4	10	14	1875?	Bored, 7 inches	.....	0	.....	do	S	.....	.....	.....
Do	5	10	14	1899	Bored, 10 inches	324	0	72	do	S	5	.....	.....
Do	6	10	16	.....	Bored, 7 inches	210	0	.....	do	S	.....	.....	.....
Do	14	10	13	.....	do	297	0	73	do	S	12	.....	.....
Do	23	19	13	.....	do	.....	0	73	do	S	[b] 2	.....	.....
Do	17	10	14	1905	do	264	0	72	do	S	[b] 4	.....	.....
Do	16	10	14	1869	Bored, 8 inches	240	0	71	do	S	12	.....	.....
Do	29	10	14	1899	Bored, 7 inches	305	0	73	do	S	58	.....	.....

[a] D, domestic; S, stock; I, irrigation; B, boilers; N, not used.

[b] Yield estimated or statement of owner taken.

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TABLE 49.—*Records of wells in Madera County*—Continued.

Owner.	Location. Section.	Township south.	Range east.	Year completed.	Type and diameter of well.	Depth of well.	Depth to water level.	Temperature of water.	Method of lift.	Use of water.	Quantity of water.	Cost of well.	Cost of machinery.
						Feet.	*Feet.*	°*F.*			*Miner's inches.*		
California Pastural & Agricultural Co.	24	10	14	.....	Bored, 6 inches	173	0	72	Artesian	S.	.....	.....	.....
Do.	28	10	15	.....	Bored, 7 inches	.....	0	73	....do	S.	[a] 3	.....	.....
Do.	21	10	15	.....	Bored, 6 inches	200	0	73	....do	S.	[a] 10	.....	.....
Do.	25	10	15	.....	Bored, 7 inches	175	0	.....	....do	S.	.....	.....	.....
Do.	6	11	16	.....	....do	175	0	.....	....do	S.	.....	.....	.....
Miller & Lux	13	11	15	.....	Bored, 8 inches	+200	0	75	....do	S.	.....	.....	.....
California Pastural & Agricultural Co.	4	11	15	.....	....do	235	0	72	....do	S.	11	.....	.....
Do.	4	11	15	.....	Bored, 7 inches	244	0	71	....do	S.	20	.....	.....
Do.	6	11	15	1899	Bored, 10 inches	262	0	.....	....do	S.	12	.....	.....
Do.	20	11	15	1899	....do	225	0	.....	....do	S.	7	.....	.....
Do.	9	11	14	.....	Bored, 7 inches	314	0	72	....do	S.	.....	.....	.....
Do.	21	11	14	.....	....do	297	0	72	....do	S.	.....	.....	.....
Do.	32	11	15	1904	....do	336	0	.....	....do	S.	26	.....	.....
Miller & Lux	35	12	14	.....	....do	16	10	.....	Hand	D, S.	.....	.....	.....
Do.	6	13	15	1892	....do	520	0	.....	Artesian	S.	.....	.....	.....
Do.	32	12	15	1877	....do	[b] 42	10	.....	Hand, wind	.....	.....	.....	.....
Do.	17	13	15	1887	....do	30	10	.....	Hand	D.	.....	.....	.....
Do.	14	13	15	1903	Dug, 4 by 5 feet	10	8	.....	....do	D, S.	.....	.....	.....
Do.	19	12	16	1897	Bored, 7 inches	45	15	.....	Wind, horse	S.	.....	.....	.....
Do.	23	12	16	1897	....do	[b] 60	15	.....	Hand, horse	S.	.....	.....	.....
Do.	17	11	16	.....	Bored, 8 inches	+200	0	74	Artesian	S.	.....	.....	.....
Do.	8	11	16	.....	....do	+200	0	73	....do	S.	.....	.....	.....
Do.	21	11	16	.....	....do	+200	0	.....	....do	S.	.....	.....	.....
Do.	34	11	16	.....	Bored, 6 inches	.....	0	74	....do	S.	Small	.....	.....
Do.	34	11	16	.....	Bored, 4 inches	.....	0	75	....do	S.	do	.....	.....
Do.	33	10	16	.....	Bored, 6 inches	44	17	66	Wind	S.	.....	.....	.....
Do.	2	11	16	1885	Bored, 4 inches	42	14	66	....do	D, S.	.....	.....	.....
Do.	14	11	16	1890	Bored, 6 inches	30	12	68	....do	D, S.	.....	$25	.....
J. Joyce	35	10	16	.....	Bored, 6 inches	45	20	67	....do	D, S.	.....	.....	.....
F. F. Moran	28	10	16	1887	....do	52	24	68	....do	D, S.	.....	.....	.....
Mrs. Cassey	23	10	16	.....	....do	50	25	67	....do	D, S.	.....	.....	.....
Olcese & Buckeran	24	10	16	.....	....do	44	25	.....	Horse	N.	.....	.....	.....
J. G. Anner	18	10	17	1890	Bored, 7 inches	58	31	67	Wind	D, S.	.....	.....	.....
H. D. Crow	30	10	17	.....	Bored, 6 inches	62	22	67	....do	D, S.	.....	30	.....
Miller & Lux	34	10	17	1887	Bored, 8 inches	.....	21	70	....do	D, S.	.....	.....	.....
Do.	27	10	17	.....	....do	.....	22	.....	Horse	S.	.....	.....	.....
Do.	22	10	17	1890	Bored, 6 inches	86	.....	.....	Wind	D, S.	.....	.....	.....
Do.	23	10	17	.....	Bored, 7 inches	80	48	67	Horse	D, S.	.....	.....	.....
Do.	26	10	17	.....	Bored, 8 inches	125	62	67	Wind	D, S.	.....	.....	.....
Pope & Talbot	20	10	18	.....	....do	98	82	.....	....do	D, S.	.....	.....	.....

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Do	8	10	18	1895	....do	180	+100	68	....do	D, S				
Archible estate	14	10	18		....do	+100	95		....do	D, S				
Do	22	10	18		....do	+110	110	69	....do	D, S				
Pope & Talbot	29	10	18		....do	125	85	67	....do	D, S				
Miller & Lux	36	10	18		Bored, 7 inches	+ 75	75	72	Horse	D, S				
Hatch & Service	1	11	18		Bored	175	+75	68	Wind	D, S				
Madera County	32	10	19		Bored, 8 inches	45	41	68	Hand	D, S				
Miller & Lux	33	10	19		....do		63	69	Wind	S				
G. D. Woolten	36	10	19	1905	Dug	28	12		Horse				149	
Bates post office	29	10	20		Bored, 6 inches	23	8	66	Wind	D, S				
G. D. Woolten	3	11	19		Bored, 8 inches	185	150	70	Horse	D, S			375	
J. R. White	19	10	20	1885	Dug	40	35	66	Wind	D, S				
Mr. Lankenshire	5	11	18	1904	Bored, 8 inches	90	40	70	....do	D, S				
Miller & Lux	1	11	17	1892	....do	55	32		Horse	D, S				
Do	11	11	17	1890	Bored, 6 inches		45		....do	S				
Do	2	11	17		Bored, 10 inches		24		....do	S				
Chas. Schmidt	11	11	17	1898	Bored, 8 inches	87		67	Wind	D, S				
H. Hall	9	11	17		....do	50	17	66	....do	D, S				
Miller & Lux	4	11	17		Bored, 4 inches	38	16		Horse	D, S				
Do	7	11	17		Bored, 6 inches	25	12	66	Wind	D, S				
Do	17	11	17		....do	32	13	65	....do	D, S				
Madera Water Co	24	11	17	1896	Bored, 8 inches	630	18							
Do	24	11	17	1896	....do	230			Steam	D	50			
Do	24	11	17	1896	....do	110								
Do	24	11	17	1896	....do	320								
Madera Canal Co	8	11	18	1896	Bored, 7 inches	85	16	72	Hand	D, S				
Santa Fe Ry. Co	16	11	18	1896	....do	175	100?		Steam	D, B	a 10			
Lankershim estate	16	11	18	1904	Bored, 6 inches	34	15		Wind	D, S			50	
M. L. Alley	17	11	18		Dug, 5 feet	22	12	70	....do	D				
A. N. Campbell-Johnston	30	11	18	1905	Bored, 8 inches	54	7	70	....do	D			50	
A. L. Sayre	32	11	18	1884	Bored, 7 inches	1,310	0	72	Not raised	N			3,400	
A. L. Sayre c	31	11	18	1903	Bored, 12 to 10 inches.	110	16	72	Gas	I	a 317			
Sacramento Bank	25	11	17	1889	Bored	50	11?	68	Hand	D, S				
Mrs. C. I. Miller	25	11	17	1895	Bored, 5 inches	90	9?		Wind	D, S			50	$60
H. Giles	25	11	17	1889	Bored, 4 inches	62	15?	70	....do	D, S			30	30
F. E. Briscol	36	11	17	1904	Bored, 5 inches		7		....do	D, S				75
W. G. Woodson	26	11	17	1875	Bored, 7 inches	78	6		Hand	D, S			65	4
Midvale Land & Fruit Co	23	11	17		....do	45	9?	70	Wind	D, S			40	60
Mr. Harris	23	11	17	1904	Bored, 10 to 9 inches.	140	9.5?	70	Gas	I	a 222		400	2,000
Do	23	11	17	1904	....do	180	9.5		....do	D, S				
Do	23	11	17	1904	....do	185	9.5		....do	D, S				
A. L. Dorsam	22	11	17	1900	Bored, 7 inches	125	18?	70	Wind	D, S			58	100
R. B. Stockton	22	11	17	1893	Bored, 6 inches	33	9		....do	D, S			33	60
H. H. Hawley	22	11	17	1893	Bored, 7 inches	26	7	68	....do	D, S			20	45
Stephen Clark	22	11	17	1891	....do	30	11		....do	D, S			25	50
L. D. Williams	27	11	17	1902	Bored, 5 inches	35	8.5		....do	D, S			17	75
Thomas Houlding	21	11	17	1892	....do	19	5.5		....do	D, S			10	35
Paolo Delavale	21	11	17		....do	18	6	67	Hand	D, S			9	4
Cesare Del Bono	28	11	17	1902	Bored, 7 inches	20	8	69	Wind	D, S			28	35

a Yield estimated or statement of owner taken. b Two wells. c Three wells.

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[illegible] estate	[illegible]	[illegible]	[illegible]		do	+106	98		do	D, S				
Do	22	10	18		do	+110	110	69	do	D, S				
Pope & Talbot	29	10	18		do	126	85	67	do	D, S				
Miller & Lux	36	10	18		Bored, 7 inches	+ 75	75	72	Horse	D, S				
Hatch & Service	1	11	18		Bored	175	+75	68	Wind	D, S				
Madera County	32	10	19		Bored, 8 inches	45	41	68	Hand	D, S				
Miller & Lux	33	10	19		do		63	69	Wind	S				
G. D. Woolten	36	10	19	1905	Dug	28	12		Horse				149	
Bates post office	29	10	20		Bored, 6 inches	23	8	66	Wind	D, S				
G. D. Woolten	3	11	19		Bored, 8 inches	185	150	70	Horse	D, S			375	
J. R. White	19	10	20	1885	Dug	40	35	66	Wind	D, S				
Mr. Lankenshire	5	11	18	1904	Bored, 8 inches	90	40	70	do	D, S				
[illegible]er & Lux	1	11	17	1892	do	55	32		Horse	D, S				
[illegible]	11	11	17	1890	Bored, 6 inches		45		do	S				
[illegible]	2	11	17		Bored, 10 inches		24		do	S				
[illegible]midt	11	11	17	1898	Bored, 8 inches	87		67	Wind	D, S				
[illegible]	9	11	17		do	50	17	66	do	D, S				
Lux	4	11	17		Bored, 4 inches	38	16		Horse	D, S				
[illegible]	7	11	17		Bored, 6 inches	25	12	66	Wind	D, S				
[illegible]	17	11	17		do	32	13	65	do	D, S				
Vater Co	24	11	17	1896	Bored, 8 inches	630	18							
[illegible]	24	11	17	1896	do	230								
[illegible]	24	11	17	1896	do	110			Steam	D	50			
[illegible]	24	11	17	1896	do	320								
[illegible]era Canal Co	8	11	18	1896	Bored, 7 inches	85	16	72	Hand	D, S				
Santa Fe Ry. Co	16	11	18	1896	do	175	100?		Steam	D, B	a 10			
Lankershim estate	16	11	18	1904	Bored, 6 inches	34	15		Wind	D, S			50	
M. L. Alley	17	11	18		Dug, 5 feet	23	12	70	do	D				
A. N. Campbell-Johnston	30	11	18	1905	Bored, 8 inches	54	7	70	do	D			50	
A. L. Sayre	32	11	18	1884	Bored, 7 inches	1,310	0	72	Not raised	N			3,400	
A. L. Sayre c	31	11	18	1903	Bored, 12 to 10 inches.	110	16	72	Gas	I	a 317			
Sacramento Bank	25	11	17	1889	Bored	50	11?	68	Hand	D, S				
Mrs. C. I. Miller	25	11	17	1895	Bored, 5 inches	90	9?		Wind	D, S			50	$60
H. Giles	25	11	17	1889	Bored, 4 inches	62	15?	70	do	D, S			30	30
F. E. Briscol	36	11	17	1904	Bored, 5 inches		7		do	D, S				75
W. G. Woodson	26	11	17	1875	Bored, 7 inches	78	6		Hand	D, S			65	4
Midvale Land & Fruit Co	23	11	17		do	45	9?	70	Wind	D, S			40	60
Mr. Harris	23	11	17	1904	Bored, 10 to 9 inches.	140	9.5?	70	Gas	I	a 222		400	2,000
Do	23	11	17	1904	do	180	9.5		do	D, S				
Do	23	11	17	1904	do	185	9.5		do	D, S				
A. L. Dorsam	22	11	17	1900	Bored, 7 inches	125	18?	70	Wind	D, S			58	100
R. B. Stockton	22	11	17	1893	Bored, 6 inches	33	9		do	D, S			33	60
H. H. Hawley	22	11	17	1893	Bored, 7 inches	26	7	68	do	D, S			20	45
Stephen Clark	22	11	17	1891	do	30	11		do	D, S			25	50
L. D. Williams	27	11	17	1902	Bored, 5 inches	35	8.5		do	D, S			17	75
Thomas Houlding	21	11	17	1892	do	19	5.5		do	D, S			10	35
Paolo Delavale	21	11	17		do	18	6	67	Hand	D, S			9	4
Cesare Del Bono	28	11	17	1902	Bored, 7 inches	20	8	69	Wind	D, S			28	35

a Yield estimated or statement of owner taken. b Two wells. c Three wells.

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TABLE 49.—*Records of wells in Madera County*—Continued.

Owner.	Location. Section.	Township south.	Range east.	Year completed.	Type and diameter of well.	Depth of well.	Depth to water level.	Temperature of water.	Method of lift.	Use of water.	Quantity of water.	Cost of well.	Cost of machinery.
						Feet.	*Feet.*	°*F.*			*Miner's inches.*		
Joseph H. Noble	29	11	17	1903	Bored, 7 inches	25	8?	.....	Wind	D, S	.....	$20	$75
H. W. Thomas	30	11	17	1894	2 inches	52	9?	.....	do	D, S	.....	50	40
Do	30	11	17	.....	Bored, 5 inches	47	11	.....	Not raised	N	.....	25	.....
G. L. Hardwell	30	11	17	.....	Bored, 7 inches	20	11	68	Wind	D, S	.....	18	50
Pope & Talbot	12	12	16	.....	Bored, 10 inches	130	10?	.....	Gas	I	a 89	.....	.....
L. & S. Sledge	32	11	17	1885	Bored, 7 inches	60	9	73	Wind	S	.....	.....	.....
Borden Farm Co	33	11	17	.....	do	26	6	.....	do	D, S	.....	25	75
Italian Swiss Colony	34	11	17	.....	Bored, 6 inches	75	11?	.....	Steam	I	7	.....	.....
C. W. Rouch	27	11	17	1901	Bored, 7 inches	34	8.5	70	Wind	D, S	.....	40	45
Dorn Vineyard	27	11	17	.....	do	+100	8	70	do	D, S	.....	.....	75
Teresa Mumphrati	35	11	17	.....	Bored, 6 inches	56	10	.....	do	D, S	.....	40	65
R. S. Vogeler	35	11	17	1897	do	115	23?	70	do	D, S	.....	80	100
S. J. Perkins	35	11	17	1897	Bored, 7 inches	45	16?	.....	do	D, S	.....	40	125
Henry Shadle	35	11	17	1902	do	40	9	68	do	D, S	.....	41	72
Alpha school district	2	12	17	.....	do	42	7	.....	do	D	.....	35	75
T. B. Wren	2	12	17	1902	do	+50	7	37	do	D, S	.....	70	50
German Savings Bank	2	12	17	1902	Bored, 5 inches	70	20?	70	Hand	D, S	.....	.....	4
A. N. Campbell-Johnston	12	12	17	.....	Bored, 7 inches	.....	7.5	.....	Wind	D, S	.....	.....	65
J. Bixby	1	12	17	1892	do	25	15?	.....	do	D, S	.....	20	60
Borden & Freeland	7	12	18	.....	Bored, 8 inches	60	11	.....	do	D, S	.....	.....	.....
J. Cunningham	6	12	18	1883	Bored, 7 inches	100	9?	.....	do	D, S	.....	125	100
Brown Bros	5	12	18	1905	do	114	16	68	Gas	I, D	8	.....	188
S. Y. Cockrum	5	12	18	1904	Bored, 10 inches	105	26	.....	do	.....	.....	.....	.....
Do	5	12	18	1904	do	168	26	.....	do	I	a 222	.....	b 3,500
Walters Bros	32	11	18	1903	Bored, 10 inches	174	11	.....	do	I	.....	.....	.....
Do	32	11	18	1903	do	104	11	.....	do				
Lankershim estate	33	11	18	.....	Bored, 7 inches	80	27	.....	Wind	D	.....	.....	.....
J. C. Secara c	4	12	18	.....	do	76	26	.....	do	D, S	.....	.....	.....
T. O. Cavin	4	12	18	1890?	do	.....	34?	.....	do	D, S	.....	.....	.....
Geo. Hollister	3	12	18	.....	do	57	28	.....	do	D, S	.....	.....	.....
Mathew Bros	3	12	18	1901	Bored, 10 inches	98	28	.....	Steam	I	.....	.....	b 2,000
Do	3	12	18	1901	do	160	28	.....	do				
H. G. Macon	3	12	18	1875	Bored, 7 inches	80	35	.....	Wind	D, S	.....	.....	.....
Miller & Lux	25	11	18	1898	do	100	50?	.....	do	D, S	.....	.....	.....
San Francisco Savings Union	1	12	18	1904	do	104	46	73	do	D, S	.....	90	140
Madera Farmers Warehouse	1	12	18	1900	Bored, 6 inches	80	44	.....	Hand	D, S	.....	.....	.....
A. E. Jones	1	12	18	.....	Bored, 7 inches	.....	44	.....	Wind and gas	D, S, I	.....	.....	180
D. B. Lavelle	11	12	18	1885	do	.....	52?	.....	Wind	D, S	.....	.....	.....
W. B. Garner	7	12	19	1902	do	101	68	.....	do	D, S	.....	.....	.....

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J. E. Stevens	33	11	19	.....	....do.....	275	80	.....	....do.....	D, S.	.....	.....	.....
Miller & Lux	35	11	19	1903	....do.....	140	96	.....	Horse	D, S.	.....	.....	.....
Wm. Healey	2	12	19	1885	.....	95	82?	74	Wind	D, S.	.....	.....	.....
J. F. Lewis	1	12	19	1888	Bored, 7 inches....	125	100?	.....	....do.....	D, S.	.....	.....	.....
P. O. Cavin	31	11	20	1904	....do.....	100	75?	.....	....do.....	D, S.	.....	.....	.....
Clapp & Butin	32	11	20	1904	....do.....	200	80	.....	....do.....	D, S.	.....	.....	.....
Mrs. Stevens	16	12	20	.....	....do.....	125	100?	.....	....do.....	D, S.	.....	.....	.....
Cobb & Littler	17	12	20	1893	....do.....	.....	100?	.....	....do.....	D, S.	.....	.....	.....
A. C. Coulthard	13	12	19	1887	....do.....	122	96	.....	....do.....	D, S.	.....	.....	.....
W. F. Hamilton	13	12	19	1896	....do.....	106	100?	.....	....do.....	D, S.	.....	.....	.....
W. T. Pitman	14	12	19	1904	....do.....	.....	.....	.....	....do.....	D, S.	.....	.....	.....
John Radley	15	12	19	1890?	....do.....	100	83?	.....	....do.....	D, S.	.....	.....	.....
Santa Fe Ry. Co	18	12	19	.....	Bored, 6 inches....	80	64?	72	....do.....	D, S.	.....	.....	.....
Georges Hely	9	12	18	1870	Bored, 7 inches....	65	20	.....	....do.....	D, S.	.....	.....	.....
Do	8	12	18	1904	....do.....	123	18	.....	Gas	I.	a222	.....	b3,000
Do	8	12	18	1904	Bored, 16 inches...	85	18	.....					
M. L. Borden	8	12	18	1903	Bored, 10 inches...	105	22	.....	Steam	I.	.....	.....	b2,000
Borden & Freeland d	7	12	18	1899	....do.....	120	16	.....	....do.....	I.	a111	.....	b5,000
H. W. Paterson	8	12	18	1903	....do.....	134	22	.....					
Do	8	12	18	1903	....do.....	96	22	.....	....do.....	I.	.....	.....	.....
Do	8	12	18	1903	Bored, 7 inches....	90?	20?	.....	Wind	D	.....	.....	.....
G. W. Mordecai	7	12	18	1880	....do.....	50	16?	.....	....do.....	S.	.....	.....	.....
Margaret and May Minor	11	12	17	1904	....do.....	60	14?	72	....do.....	D, S.	.....	60	60
J. L. Butin	10	12	17	1904	Bored, 8 inches....	152	5?	.....	Gas	I.	.....	350	1,400
Do	10	12	17	1904	....do.....	147	5?	.....					
J. S. Osborn	10	12	17	1883	Bored, 7 inches....	40	12?	.....	....do.....	D, S.	.....	40	175
John Conley	10	12	17	1904	....do.....	53	6	.....	Wind	D, S.	.....	45	50
A. Wiehe	9	12	17	.....	....do.....	.....	6.5	70	....do.....	S.	.....	.....	50
Louisa Pinasco	9	12	17	1899	....do.....	75	7	.....	Horse	I.	.....	65	300
A. E. Waters	9	12	17	1897	....do.....	+100	6	.....	Wind	D, S.	.....	126	60
J. P. Gallener	9	12	17	1893	Bored, 8 inches....	56	7	70	....do.....	D, S.	.....	55	35
Italian Swiss Colony	17	12	17	.....	Bored, 7 inches....	.....	9	70	....do.....	D, S.	.....	.....	75
Yosemite Stage & Turnpike Co	16	12	17	1888?	....do.....	35	7?	.....	....do.....	D, S.	.....	30	75
T. L. Noble	15	12	17	1903	....do.....	50	5?	68	....do.....	D, S.	.....	40	60
Sam Rowe	22	12	17	.....	....do.....	42	12?	70	Hand	D, S.	.....	35	4
German Savings & Loan Society	26	12	17	.....	....do.....	.....	13	.....	Wind	D, S.	.....	.....	60
P. C. Easton	25	12	17	.....	....do.....	.....	20?	.....	....do.....	D, S.	.....	.....	60
G. E. & A. K. Ripperdan	36	12	17	1887	Bored, 8 inches....	70	32?	.....	....do.....	D, S.	.....	70	40
E. McGarvin	19	12	18	1905	Bored, 12 inches...	50	32?	.....	Steam	I.	a70	.....	b1,250
Do	19	12	18	.....	Bored, 7 inches....	80	30?	.....	Wind	D, S.	.....	.....	.....
S. Shephard	30	12	18	1885	....do.....	60	28	.....	....do.....	D	.....	.....	.....
E. G. Hope	29	12	18	1875	Bored, 8 inches....	68	28	.....	....do.....	D, S.	.....	68	175
Do	28	12	18	1880	....do.....	82	26	.....	....do.....	D, S.	.....	82	154
J. H. Shedd e	28	12	18	1875	Bored, 7 inches....	100	42	.....	....do.....	D, S.	.....	200	.....
A. Lusk	34	12	18	.....	Bored, 8 inches....	.....	45	.....	....do.....	D, S.	.....	.....	.....
J. L. Price	33	12	18	.....	....do.....	80	40?	.....	....do.....	D, S.	.....	.....	.....
A. A. Skaggs e	31	12	18	1874–5	....do.....	75	37	.....	....do.....	D, S.	.....	.....	.....
Miller & Lux	1	13	17	1900	Bored, 7 inches....	100	30?	.....	Horse	D, S.	.....	85	.....
Do	2	13	17	1893	Bored, 10 inches...	125	35	72	Wind	D, S.	.....	150	60
Do	5	13	17	1893	....do.....	100	30	72	....do.....	D, S.	.....	100	60

a Yield estimated or statement of owner taken. b Cost of well and equipment combined. c Three wells. d Four wells. e Two wells.

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FRESNO COUNTY.

GENERAL CONDITIONS.

The part of Fresno County within San Joaquin Valley contains one of the largest and most intensively cultivated areas as well as a portion of the most barren territory in the Great Central Valley. The rainfall, which gradually decreases in amount from the mouth of the Sacramento southward, is so slight in Fresno County that dry farming is precarious, hence most of the unirrigated land is also uncultivated and is used only as range. Around Fresno and south and east of that city luxuriant crops of great diversity are grown; raisin, table, and wine grapes, peaches, almonds, apricots, and other high-priced products are chiefly cultivated, while hay and cereals yield good returns in the less thickly settled portions of Kings River delta.

This rich and populous region is irrigated by gravity water, distributed by a network of canals that take their supply from the river. These irrigation systems have been fully described by Grunsky.[1]

A later paper, by Lippincott,[2] dealing with the possibility of storage and the development of water power on Kings River, embodies the results of a close study of the ground waters and their relation to alkali conditions by Louis Mesmer and Thomas H. Means. From this report (pp. 53, 54, and 85) the following quotations are taken:

> The natural drainage of these lands is toward the southwest, at the rate of about 6 feet to the mile. The soil is largely granitic sand, and below an average depth of 10 or 15 feet it is saturated with water. The surface water is somewhat alkaline, and therefore it is not advisable to pump it for irrigation. Water below a depth of 50 feet can be considered satisfactory for irrigation. This is based on tests of more than 800 wells in the district, some of them being in sections where there were the strongest surface alkaline indications. In every case this lower water was found to be good, and when the strata near the surface are penetrated it rises to the elevation stated. There have been few attempts to pump water in larger quantity than is required for domestic purposes. A 2-inch screw pipe, put down to an average depth of 50 feet, landing the pipe on a stratum of clay, and then boring through the clay and allowing the water to come in from the bottom of the hole, is always ample for this purpose.
>
> * * * * * * *
>
> A few small pumping plants have been installed—one 5 miles east of Fresno, on Minnewawa ranch; several around Selma, and two near Wildflower—which yield at least 0.5 second-foot to a 7-inch unperforated well not more than 70 feet deep, with a lift not to exceed 20 feet in any case. Wells of 10-inch or 12-inch casing should be put down to a depth of about 100 feet on an average, and should not be perforated above 50 feet below the surface, thus shutting off all possible chance of drawing from the more or less alkaline surface water. It is probable that wells of this size and depth would each furnish 1.5 second-feet.
>
> * * * * * * *
>
> The result of pumping * * * would be to improve the conditions rather than to increase the trouble from alkali. The water table would be lowered sufficiently to permit the washing down of the alkali salts, and the salts, instead of being confined to the surface layers of the soil, would gradually be distributed * * * and by this

[1] U. S. Geol. Survey Water-Supply Paper 18, pp. 39 et seq., 1898. Out of print. May be consulted in libraries.

[2] U. S. Geol. Survey Water-Supply Paper 58, 1902. Out of print. May be consulted in libraries.

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dilution rendered harmless. The lowering of the water table would be of the greatest assistance to the reclamation of the lands already alkaline, and would probably permit this reclamation without extensive underdrains.

Other reports dealing with the problem of alkali and drainage have been prepared by Fortier, Mackie, and Cone.[1] In a report by Lewis A. Hicks on the "Generation and transmission of electric power and installation of pumping plants," included in Water-Supply Paper No. 58, an estimate has been made of the cost of water pumped from the ground-water supply by electric power generated on Kings River. The estimates are made on the basis of 100 pumping stations, each with a maximum capacity of 5 second-feet and an average lift of 45 feet, and the probable cost of the water produced is given as 50 cents per acre-foot when the pumping plants operate 328½ days per year and $1.43 when the pumping plants operate 100 days per year.

Among the conclusions reached by Mr. Lippincott[2] after a thorough investigation of conditions on the Kings River delta are the following

Pumping plants can be established and operated which will furnish 1,000 acre-feet of water per day at a cost not much greater than that now paid for gravity water from the canals, to supplement the present summer supply or to extend the irrigated areas.

The operation of the pumping plants will partially if not wholly prevent the rising of alkali to the surface of irrigated lands.

The rise of the ground waters presents a difficult problem in practically all of the delta lands of the San Joaquin Valley, and is merely particularly well exemplified in the Kings River delta in Fresno County. Mr. Grunsky states that the rise in ground waters since the beginning of irrigation is from 10 to as much as 50 feet in parts of the delta. One great difficulty that arises in dealing with the problem is due to the fact that the injury is done in one locality while a large part of the cause may be in another. The lower delta lands are the chief sufferers from the rise of the ground waters, but the cause is to be found in the irrigation on the higher lands as well as on those affected. Over portions of the central artesian basin and about its borders the ground waters have always stood close to the surface, and much of the land was impregnated with alkali before there was any settlement in the valley. The effect of the irrigation on the higher lands has been to extend this saturated alkali zone slowly up the slope toward the eastern margin of the valley until it has encroached to a certain extent upon lands that were valuable.

Without storage the gravity waters will not serve an acreage greatly in excess of that supplied by them now, and the pumping

[1] Mackie, W. W., Reclamation of white-ash lands affected with alkali at Fresno, Cal.: U. S. Dept. Agr. Bur. Soils Bull. 42, 1907.

Fortier, Samuel, and Cone, V. M., Drainage of irrigated lands in the San Joaquin Valley, Cal.: U. S. Dept. Agr. Off. Exper. Sta. Bull. 217, 1909.

Cone, V. M., Irrigation in the San Joaquin Valley, Cal.: U. S. Dept. Agr. Office Exper. Sta. Bull. 239, 1911.

[2] Lippincott, J. B., Storage of water on Kings River, California: U. S. Geol. Survey Water-Supply Paper 58, p. 96, 1902.

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plants that must be installed to secure future growth will in addition serve a most valuable function in drainage, tending to prevent the extension of alkali conditions and aiding in the reclamation of lands already containing too much alkali.

FLOWING WELLS.

The flowing wells of the artesian belt of Fresno County are sparsely scattered over a broad area along the trough of the valley. In 1906 there were only about 40 of them, ranging in depth from less than 100 to 1,500 feet, the latter being the depth of one of the wells belonging to the Johns estate, north of Summit Lake. In the district adjacent to Lemoore, south of Kings River, small flows, sufficient for stock and domestic use, are obtained at 150 feet and less, but farther north no shallow wells are found.

Those on the James and Herminghause ranches, south of San Joaquin River, are 600 to 800 feet deep. The flowing wells of the larger ranches were bored generally to obtain a supply of water for stock at times when none is available in the sloughs and irrigating ditches. Irrigation in these large holdings is as yet accomplished only during the flood season when abundant gravity water is available for lavish use. The possibility of using ground waters for such purposes is scarcely considered, although on one of the James ranches the water from a flowing well is used to irrigate about 50 acres of alfalfa.

The great west-side plains, with their productive soil, freedom from hardpan, good drainage, and favorable situation, are nonproductive because of their aridity, and must remain so until water can be applied to them. The ground-water plane seems to be nearly horizontal, such evidence as is at hand indicating a slope of only about 2 to 5 feet per mile; hence it is nearly as far to ground water beneath any part of these plains as the plains themselves are above the lowest part of the valley. If experiments should prove that these lands will successfully produce citrus fruits or other high-priced products, then it may be that the water can be pumped to them from the valley and the venture made commercially practicable despite the great expense involved, for it is to be remembered that water is pumped to heights of several hundred feet in Tulare and San Bernardino counties in localities where it can be used on good citrus lands with an excellent margin of profit.

At present the west slope is almost devoid of permanent residents. There are perhaps a dozen settlers between Panoche Creek and the Coalinga branch of the Southern Pacific. Sheep camps, occupied temporarily in winter, are scattered over them. In the early nineties a few seasons of heavy rainfall led to settlement about Huron, and two or three crops of grain were harvested, but since then there has usually not been sufficient rainfall to mature a crop, and the plains

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have been abandoned to the sheep men, who lease the grazing privileges from the large landholders, notably the Southern Pacific Co.

QUALITY OF THE WATER.

The water from wells 20 to 200 feet deep that were tested on the east side of the county would be considered entirely suitable for use in irrigation except that within about 10 miles of Kings River Slough. In general, calcium carbonate waters of moderate mineral content are encountered on the east side, but the characteristic alkali alteration takes place toward the axis of the valley, and the upper waters are less desirable, though not absolutely harmful. According to the tests wells 100 to 300 feet deep at Fresno yield supplies containing but from 120 to 300 parts per million of mineral matter. The shallow wells yield somewhat harder water, and it is reported that the water at 600 feet is good, while a 500-foot well 6 miles northeast yields water like that of the 100 to 300 foot wells in the city. Doubtless wells could be sunk to 1,000 feet without danger in the deltas east of a line joining Jamesan and Caruthers, if it were necessary or desirable to go so deep as that for sufficient supply. Determinations by means of the electrolytic cell of the total solids in 854 ground waters in Kings River delta, including parts of Kings and Tulare counties, as well as the greater portion of the east side of Fresno County, are published in Water-Supply Paper 58.[1] Most of the wells from which the samples were taken are less than 100 feet deep, none in Fresno County being more than 300 feet deep. According to these estimates the shallow waters are moderately low in mineral content; total solids exceed 300 parts per million in only 5 per cent of the samples, and only two among several hundred samples tested in Fresno County contain more than 600 parts per million of dissolved matter.

The quality of east-side waters deeper than 1,200 feet is unknown for no wells approaching that depth could be tested. As far south as Fresno County wells more than 1,200 feet deep strike salt water, but south of that county wells as deep as 2,000 feet yield fresh water, and it is therefore evident that the final disappearance southward of excessive chlorides in the deep supplies takes place somewhere between Madera and Corcoran and probably within Fresno County. Some of the wells 550 to 800 feet deep near Jamesan Colony give brackish water, but this is no indication of the possibilities farther east, for water from moderately deep flowing wells elsewhere in the valley is better in proportion to the distance of the wells east of the axis. The water of the 1,200-foot well in sec. 2, T. 17 S., R. 18 E., contains only 135 parts per million of chlorine and 610 parts of total solids; the 2,250-foot well in sec. 14, T. 18 S., R. 18 E., contains 279 parts of chlorine and 872 parts of solids; that is, neither

[1] Lippincott, J. B., Storage of water on Kings River, California: U. S. Geol. Survey Water-Supply Paper 58, 1902.

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water, though both are near the axis, where the alkali content of the waters should be greatest, approaches in saltness or in mineral content the very deep waters farther north.

The west side of the county is mostly semiarid sheep range, but the possibility of producing good crops by the use of ground water along the lower eastern edge of this west-side plain is being demonstrated around Mendota and Huron, and on several isolated farms between these settlements. Barley, Egyptian corn, alfalfa, and general garden truck are being irrigated by pumping in T. 14 S., R. 14 E.; T. 15 S., R. 14 E.; T. 15 S., R. 15 E.; and T. 20 S., R. 17 E. The ground water out on the plains is highly gypsiferous, more than 60 per cent of the total residue consisting of calcium, magnesium, and sulphate. Such water is very bad for boiler use because treatment to remove the scale-forming constituents and to neutralize the corrosive tendencies increases the foaming ingredients to so great amount that excessive foaming is likely to occur. The content of alkali is not excessive, however, and does not destroy, though it reduces, the value of the water for irrigation. The area in which such ground supplies are typical extends from South Dos Palos to the Kings-Fresno county line between the artesian belt on the east and the foothills of the Coast Range on the west. Only one well in it more than 250 feet deep was tested, and that well, 1,200 feet deep in sec.11, T. 20 S., R. 17 E., is said to be unproductive below 400 feet; it is probable that any waters that may be encountered below 250 feet are similar to those above that depth in their essential characteristics.

Plate III (p. 102) and figure 3 (p. 107) show the relation between the location and depth of wells in the artesian area and the sulphate content of their waters. Alkali bases are predominant in all of them, but otherwise they differ greatly from one another in composition and concentration. Sodium sulphate waters of high total solids are characteristic west of the slough and sodium chloride and sodium carbonate waters east of it within the limits of the artesian area. They are fair to very poor for irrigation, and supplies from shallower, nonflowing wells are superior for general use. The water of the 2,250-foot well in sec. 14, T. 18 S., R. 18 E., comes from one of the deepest borings in the valley. The analysis by Eaton shows it to be much less strongly mineralized than other supplies west of the slough, but very poor for irrigation because of its high content of bicarbonate, chloride, and alkalies; it is understood that the water killed crops to which it was applied. Its content of foaming constituents is great enough to make it undesirable for boiler use. The fact that it contains practically no sulphate, though all the other waters in the immediate vicinity are high in that constituent, indicates that the well passes through the typical west-side sediments and draws its supply from beneath them. Greater quantities of gas than are present in the other artesian waters of the county escape from the casing.

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a C., c

c Two wells 45 and 75 feet deep.

Owner.	D	Classification.				Analyst.
		ral nt.	Chemical character.	Quality for boilers.	Quality for irrigation.	
Pacific Coast Oil Co....	.....	....	$Na\text{-}SO_4$....	Very bad .	Fair.....	Pacific Coast Oil Co.
J. G. James Co.....	Nov.	....	Na-Cl.....	...do.....	...do.....	F. M. Eaton.
F. C. Stillman.....	Nov.	....	$Ca\text{-}SO_4$....	...do.....	...do.....	Do.
Joseph Mouren.....	Nov.	....	...do.....	...do.....	...do.....	Walton Van Winkle.
Sanford & Claverias....	.....	igh.	...do.....	...do.....	...do.....	F. M. Eaton.
Southern Pacific Co....	Oct.	te..	$Na\text{-}CO_3$...	Fair.....	Good....	Southern Pacific Co.
Manuel Nunez.....	Nov.	....	Na-Cl.....	Very bad .	Poor....	F. M. Eaton.
Pacific Coast Oil Co....	.....	....	$Na\text{-}SO_4$....	...do.....	Fair.....	Pacific Coast Oil Co.
Southern Pacific Co....	June	te..	$Ca\text{-}CO_3$....	Fair.....	Good....	Southern Pacific Co.
Do.....	July	....	...do.....	...do.....	...do.....	Do.
Do.....	June	....	...do.....	...do.....	...do.....	Do.
Santa Fe Ry. Co.....	Oct.	....	...do.....	...do.....	...do.....	Kennicott Water Softener Co.
Fresno Brewing Co.....	Nov.	....	...do.....	Good.....	...do.....	F.M. Eaton.
Do.....	.....	....	...do.....	Fair.....	...do.....	Walton Van Winkle.
Southern Pacific Co....	June	....	$Na\text{-}CO_3$...	Good.....	Fair.....	Southern Pacific Co.
Miller & Lux.....	Oct.	....	...do.....	...do.....	Good....	Do.
Pacific Coast Oil Co....	Oct.	....	$Na\text{-}SO_4$....	Very bad..	Fair.....	Do.
M. F. Tarpey.....	Nov.	te..	$Ca\text{-}CO_3$....	Fair.....	Good....	F. M. Eaton.
Southern Pacific Co....	Dec.	....	$Na\text{-}CO_3$...	Good.....	...do.....	Southern Pacific Co.
A. R. Gilstrap.....	Nov.	....	$Ca\text{-}CO_3$....	Fair.....	...do.....	F. M. Eaton.
Southern Pacific Co....	Apr.	....	...do.....	...do.....	...do.....	Southern Pacific Co.
Santa Fe Ry. Co.....	Oct.	....	...do.....	...do.....	...do.....	Kennicott Water Softener Co.

deep.
on and aluminum.
matter, 11 parts.

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The accompanying well records secured by the Geological Survey in 1906 and earlier represent practically all of the important wells in existence at that date and many others that were examined to determine water levels and quality of water. Developments that have taken place since that date are not represented.

TABLE 52.—*Records of wells in Fresno County.*

Owner.	Location.			Year completed.	Type and diameter of well.	Depth of well.	Depth to water level.	Temperature of water.	Method of lift.	Use of water.[a]	Yield.	Cost of well.	Cost of machinery.
	Section.	Township south.	Range east.										
						Feet.	*Feet.*	°*F.*			*Miner's inches.*		
Miller & Lux	33	10	13	1902	Bored, 7 inches	14	10	.....	Hand	D, S	.....	.....	.....
Do	6	11	13	1903	....do	480	0	.....	Artesian	S	.....	.....	.....
Do	10	11	13	1900	Dug, 4.5 by 4.5 feet	22	10	.....	Wind	D, S	.....	.....	.....
A. D. Johns	7	11	13	1902	Dug, 2 feet	10	7	70	Hand	D, S	.....	.....	.....
C. W. Slayton	14	11	12	1905	Dug, 2.5 feet	14	7	.....	Wind	D, S	.....	.....	.....
F. B. Marks	13	11	12	1895	Dug, 1.5 feet	15	7	.....	....do	D, S	.....	.....	.....
J. Glidden	24	11	12	1893	Dug, 2 feet	28	7	.....	....do	D, S	.....	.....	.....
R. D. Conrow	24	11	12	1894	Dug, 1.75 feet	15	7	71	Hand	D, S	.....	.....	.....
Geo. W. Martin	24	11	12	1905	Dug, 2 feet	12	7	70	....do	D	.....	.....	.....
Pacific Coast Oil Co	23	11	12	1905	Bored, 10 inches	408	10	.....	.....	.....	.....	.....	.....
Miller & Lux	19	11	13	1905	Dug, 2 feet	22	7	.....	Wind	D, S	.....	.....	.....
Do	30	11	13	1887	Bored, 8 inches	93	7.5	.....	Horse	S	.....	.....	.....
Do	24	11	13	1899	Dug, 5 by 5 feet	16	10	.....	Wind	D, S	.....	.....	.....
Do	24	11	13	.....	Bored, 8 inches	65	10	72	Hand	S	.....	.....	.....
Do	33	11	13	1894	Bored, 7 inches	437	0	70	Artesian	S	4	.....	.....
Do	8	12	14	1882	....do	40	10	.....	Wind	D	.....	.....	.....
Do	28	12	14	.....	Dug, 5 by 5 feet	22	10	.....	....do	S	.....	.....	.....
Southern Pacific Co	29	12	14	.....	Bored, 8 inches	300	0	67	Steam	N	.....	.....	.....
Miller & Lux	9	13	13	.....	Bored, 7 inches	202	80	.....	Horse	S	.....	.....	.....
Do	34	12	12	.....	....do	229	73	.....	Wind, horse	S	.....	.....	.....
Do	22	12	11	.....	....do	169	80	.....	....do	S	.....	.....	.....
Do	34	13	12	.....	....do	260	145	.....	Horse	S	.....	.....	.....
Do	34	13	14	.....	....do	240	60	.....	....do	S	.....	.....	.....
Pacific Coast Oil Co	22	13	14	1905	Bored, 10 inches	700	0	78	Artesian	I, D, B	6	.....	.....
A. J. Arnaudon	31	13	15	1900	Bored, 8 inches	285	18	.....	Wind	D	.....	[b]	$1,500.00
Southern Pacific Co	31	13	15	1889	....do	640	0	78	Artesian, steam	D	[c] 7	.....	.....
Bliss Bros	35	9	14	1875?	Bored, 6 inches	25	.....	.....	.....	.....	.....	.....	.....

[a] D, domestic; S, stock; I, irrigation; B, boilers; N, not used; W, winery; R, roads.
[b] Cost of well and equipment combined.
[c] Yield estimated or statement of owner taken.

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TABLE 52.—*Records of wells in Fresno County*—Continued.

Owner.	Location. Section.	Township south.	Range east.	Year completed.	Type and diameter of well.	Depth of well.	Depth to water level.	Temperature of water.	Method of lift.	Use of water.	Yield.	Cost of well.	Cost of machinery.
						Feet.	*Feet.*	°*F.*			*Miner's inches.*		
Stearns & Hysinger	12	14	14	1904	Bored, 16 inches	200	40	.....	Steam	.....	.....	.....	.....
A. J. Arnaudon	21	14	14	1889	Bored, 8 inches	190	33	.....	Hand	S	.....	$400	.....
C. Boyer	33	14	14	1889	....do	175	90	.....	Horse	S	.....	.....	.....
Miller & Lux	26	14	13	.....	Bored, 7 inches	124	93	.....	....do	S	.....	.....	.....
Do	33	14	13	.....	....do	229	133	.....	....do	S	.....	.....	.....
Herminghause Ranch	2	14	15	.....	Bored, 8 inches	750	0	78	Artesian	S, I	20	.....	.....
Do	30	13	16	.....	.....	650	0	.....	....do	S	[a] 10	.....	.....
J. G. James Co	10	14	16	1887	Bored, 7 inches	800	0	78	....do	S	[a] 16	1,650	.....
Southern Pacific Co	14	14	16	.....	....do	200	7.5	.....	Hand	D	.....	.....	.....
J. G. James Co	7	14	17	.....	Dug	11	9	64	....do	D, S	.....	.....	.....
Mrs. G. W. Bryan	36	13	17	.....	.....	120	15	.....	Gas	I	.....	.....	[b]$2,500.00
Do	36	13	17	.....	.....	70	15	.....	....do		.....	.....	
James Cull	25	13	17	.....	Bored, 5 inches	.....	12	.....	Wind	D	.....	.....	.....
A. E. Wood	19	13	18	.....	Hydraulic, 2 inches	50	10	72	Hand	D, S	.....	.....	.....
Peter J. Wolf	29	13	18	.....	....do	55	11	.....	....do	D, S	.....	.....	.....
Sharon estate	21	13	18	.....	Bored, 7 inches	60	11	70	Wind, horse	D, S	.....	.....	.....
Do	21	13	18	1904	Bored, 10 inches	200?	12	.....	Gas	I	[a] 300	.....	.....
Do	21	13	18	1904	....do	200?	12	.....	....do	I	[a] 300	.....	.....
Henry Sahm	33	13	18	.....	.....	50	10	.....	Hand	D, S	.....	.....	.....
Kutner & Goldstein	32	13	18	1905	Bored, 16 inches	160	15	.....	Gas	I	.....	.....	.....
Do	32	13	18	.....	Bored, 8 inches	42	11	72	Hand	D, S	.....	.....	.....
Mr. Smith	5	14	18	.....	Bored, 1.5 inches	20	11	.....	....do	D	.....	.....	.....
J. E. Howard	8	14	18	1905	Hydraulic, 2 inches	58	12	.....	....do	D, S	.....	20	.....
James Garner	9	14	18	.....	Bored, 2 inches	69	12	.....	....do	D	.....	25	.....
Southern Pacific Co	7	14	18	.....	Bored, 8 inches	640	6	.....	Wind, steam	B	.....	.....	.....
E. A. Manning	32	14	18	1894	Hydraulic, 2inches	100	7	.....	Hand	D, S	.....	.....	.....
Do	31	14	18	1894	....do	100	6	.....	....do	D, S	.....	.....	.....
J. G. James Co	10	15	17	1886–7	Bored, 8 inches	700	0	.....	Artesian	S	Small.	1,370	.....
Do	9	15	17	1886–7	....do	800	0	74	....do	S	40	1,850	.....
Do	12	15	16	1886–7	Bored, 7 inches	800	0	77	....do	D, S	10	1,650	.....
Do	25	15	16	1886–7	Bored, 8 inches	825	0	76	....do	I, S	.....	1,700	.....
Do	26	15	16	.....	Dug, 1.5 feet	25	10	.....	Wind	D, S	.....	.....	.....
Do	34	15	16	.....	Bored, 5 inches	24	15	68	Hand	S	.....	.....	.....
Do	28	15	16	.....	....do	34	11	.....	Not raised	N	.....	.....	.....
Do	20	15	16	1890?	....do	70	12	.....	Hand	D, S	.....	.....	.....
Do	19	15	16	1886–7	Bored, 8 inches	700	0	79	Artesian	S	[a] 2	1,370	.....
Do	18	15	16	.....	Bored, 5 inches	60	13	.....	Wind	S	.....	.....	.....
School district	18	15	16	.....	Bored, 2 inches	60	14	67	Hand	D	.....	.....	.....

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J. G. James Co.	13	15	15	.....	Bored, 5 inches	50	8	.....	Wind	S	.....	.....	.....
J. N. Daniels	12	15	15	.....	Dug	20	13	.....	....do	S	.....	.....	.....
Pacific Coast Oil Co.	11	15	15	1904	Bored, 8 inches	733	0	76	Artesian, steam	D, B	11	.....	.....
Sheep camp	3	15	15	.....	Bored, 5 inches	9	7	72	Not raised	N	.....	.....	.....
J. G. James Co.	35	15	16	.....	....do	43	23	66	Wind	S	.....	.....	.....
Do	36	15	16	.....	....do	42	10.5	.....	....do	D, S	.....	.....	.....
Do	32	15	17	.....	Dug	15	12	.....	....do	S	.....	.....	.....
Do	25	15	17	1886–7	Bored, 8 inches	750	0	80	Artesian	S	[a] 31	1,560	.....
Abandoned ranch	12	16	16	.....	Bored, 10 to 8 inches.	+200	13	.....	Not raised	N	.....	.....	.....
Miss Miller	20	16	17	.....	Bored, 7 inches	70	11	70	Hand	D, S	.....	.....	.....
Hellum & Co.	15	16	17	1903	....do	83	13	.....	Wind	S	.....	.....	.....
Do	14	16	17	1903	Bored, 5 inches	80	12	68	Wind, horse	D, S	.....	.....	100.00
Do	14	16	17	1904	Bored, 10 inches	690	0	75	Artesian	I	[a] 8	.....	.....
Mrs. Yates	22	16	17	1898	Bored, 7 inches	50	11	.....	Wind	D, S	.....	.....	.....
New Hope school district	27	16	17	1895	Bored, 5 inches	60	12	.....	Hand	D	.....	.....	.....
Pacific Coast Oil Co.	8	17	17	1905	Bored, 8 inches	1,100	0	.....	Artesian	B	.....	.....	.....
Burrell estate	5	17	18	1896	Bored, 7 inches	50	13	.....	Hand	S	.....	.....	.....
Marks Bros.	8	17	18	1895?	....do	80	15	71	Wind	D, S	.....	.....	50.00
Burrell estate	9	17	18	1893	....do	80	12	.....	....do	D, S	.....	125	65.00
J. R. Hite	17	17	18	.....	....do	122	12	70	....do	D, S	.....	175	60.00
Wheatville school district	17	17	18	.....	....do	110	12	72	....do	D	.....	.....	.....
J. R. Hite	15	17	18	1890	Bored, 8 inches	600	0	76	Artesian	I, S	.....	.....	.....
Burrell estate	10	17	18	.....	Bored, 7 inches	75	12	.....	Wind	D, S	.....	.....	.....
Josephine Smith	34	16	18	1890	Dug, 2½ feet	35	12	.....	....do	D	.....	.....	.....
Burrell estate	2	17	18	1888	Bored, 8 inches	1,200	0	78	Artesian	D, S	.....	.....	.....
H. Jensen	1	17	18	.....	Dug, 2 feet	24	12	69	Wind	D, S	.....	.....	.....
C. L. Camellones	6	17	19	1904	Bored, 5 inches	52	12	.....	....do	D	.....	.....	.....
L. E. Vance	6	17	19	1891?	....do	56	14	70	Wind, hand	D, S	.....	.....	.....
Ipsen Bros.	6	17	19	1904	....do	77	15	.....	Hand	D, S	.....	75	.....
Mrs. Eva Rowntree	5	17	19	1890?	....do	75	15	.....	Wind	D, S	.....	.....	.....
Henry Jensen	4	17	19	.....	....do	54	12	.....	Hand	S	.....	39	.....
Mr. Browning	17	17	19	.....	Bored, 8 inches	700	0	77	Artesian	S	17	.....	.....
William Johns estate	21	17	19	1890	....do	1,500	0	82	....do	S	23	1,500?	.....
A. J. Vancleef	22	17	19	.....	Bored, 5 inches	40	10	71	Wind	D	.....	25	65.00
C. W. Baker	32	17	19	1903	....do	37	8	.....	Hand	D, S	.....	.....	.....
William Johns estate	28	17	19	1890	Bored, 8 inches	1,200	0	80	Artesian	S	[a] 15	1,200	.....
Peter Gobby	27	17	19	1903	Dug, 1½ feet	30	8	.....	Wind	D	.....	.....	75.00
J. Q. Hancock	23	17	19	.....	Bored, 5 inches	80	9	69	....do	D, S	.....	.....	.....
W. J. Brawner	24	17	19	1905	....do	82	6	70	Hand	D	.....	57	.....
R. S. Gobbe	19	17	20	.....	....do	18	6	72	Wind	D, S	.....	.....	85.00
J. Fleharty	29	17	20	.....	Dug, 2 feet	16	10	.....	Hand	D	.....	.....	.....
J. N. Fleharty	29	17	20	.....	Bored, 5 inches	55	10	70	....do	D	.....	27	.....
J. W. Crawford	21	17	20	1903	....do	46	10	.....	....do	D, S	.....	23	.....
L. B. Wheeler	22	17	20	1880	....do	56	16	.....	Wind	D, S	.....	30	40.00
A. McDonald	1	17	20	1885	Bored, 7 inches	40	10	.....	Hand	D, S	.....	25	.....
Southern Pacific Co.	1	17	20	.....	Bored, 8 inches	700	0	80	Artesian, steam, wind.	B	[c] 1	.....	.....
J. E. Lewis	21	17	20	1902	Bored, 5 inches	118	13.5	70	Hand	D, S	.....	75	.....
P. L. Rousseau	27	17	20	1903	....do	48	8?	69	Wind	D, S	.....	28	45.00
H. E. Center	26	17	20	.....	....do	39	4	70	Hand	D	.....	20	.....

[a] Yield estimated or statement of owner taken.

[b] Cost of well and equipment combined.

[c] Normal flow without pumping.

98205°—WSP 398—16——16

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TABLE 52. *Records of wells in Fresno County*—Continued.

Owner.	Location. Section.	Township.	Range.	Year completed.	Type and diameter of well.	Depth of well.	Depth to water level.	Temperature of water.	Method of lift.	Use of water.	Yield.	Cost of well.	Cost of machinery.
						Feet.	Feet.	°F.			Miner's inches.		
L. G. Boggs	24	17	20		Bored, 8 inches	40	8	71	Hand	[illegible]			
Laguna de Tache ranch	24	17	20		do	80	8		do	[illegible]			
Mr. Fike	19	17	21		do	46	8	70	do	[illegible]			
Grant school district	19	17	21		do	48	8	70	do	[illegible]			
Mr. Hurley	19	17	21		do	60	10		Wind	[illegible]			
E. P. Blanchard	20	17	21		do	60	9	68	Hand	[illegible]			
J. W. Buble	21	17	21		do	78	9	60	do	[illegible]		610	
L. A. Nares	21	17	21		Bored, 6 inches	60	8	66	do	[illegible]			
Nares & Saunders	22	17	21	1902	Bored, 10 inches	200	8		Gas	[illegible]	8		
J. H. Cleveland	28	17	21	1900	Bored, 8 inches	42	7.8		Hand	[illegible]			
D. F. Lumsden	29	17	21	1901	do	80	9	60	do	[illegible]		18	
J. R. Ryder	25	17	20		Bored, 14 inches	40	8	70	do	[illegible]			
J. E. Woodworth	34	17	20		Bored, 8 inches	46	8	68	do	[illegible]		34	
Leguna school district	27	17	20		do	54	8	70	do	[illegible]			
James Hay	27	17	20		do	46	4		do	[illegible]		41	
Mr. Molen	3	18	20		do	50	10	72	do	[illegible]			
Manuel de Mecedo	3	18	20		do	80	13		do	[illegible]			
Laguna de Tache ranch	4	18	20		Bored, 7 inches	45	11.8	70	do	[illegible]			
Joseph Jubrisil	5	18	19		do	48	14	70	Wind	[illegible]			
A. H. Brown	6	18	19	1880	Bored, 8 inches	100	8		do	[illegible]			
Chas. W. Brown	6	18	19	1888	do	100	8		do	[illegible]			
Mr. Awalt	6	18	19	1880	Bored, 7 inches	100	11		do	[illegible]		138	680 00
Mr. Goodrich	1	18	18	1902	Bored, 8 inches	87	19	71	Hand	[illegible]			
H. Clausen	35	17	18	1895?	Bored, 7 inches	69	16		Wind	[illegible]		100	
W. Corbeley	34	17	18		Bored, 8 inches	48	16		Hand	[illegible]			
T. Cowan	27	17	18	1890	Bored, 7 inches	114	16		Wind	[illegible]		178	
Henry Munson	21	17	18	1897	do	199	9	70	do	[illegible]			
Do	22	17	19	1898	Bored, 6 inches	94	18	70	do	[illegible]			
Manuel Nuñes	9	18	18		Bored, 7 inches	80	20		Horse	[illegible]			
Joseph Mouren	6	18	18	1891	do	118	85		do	[illegible]		200	
Joseph Taix	12	18	17	1897	do	114	49		Wind	[illegible]		200	80 00
Mrs. Cravelio	24	17	17		Bored, 6 inches	100	88?		Horse	[illegible]			
H. R. McCord	14	18	16	1888	Bored, 7 inches	250	78		Wind	[illegible]			
Pedro Arriet	18	18	16	1902	do	185	120		Horse	[illegible]		147	
F. G. Ladd	12	18	15	1903	do	256	160		do	[illegible]			
Sheep camp	26	18	18		do	60	36		Not raised	[illegible]			
Pacific Coast Oil Co	36	18	18	1903	Hydraulic, 8 to 6 inches.	1,178	207	80	Compressed air	[illegible]	7	9,000	

Sheep camp	19	18	19		Bored, 6 inches	52	27		Not raised	N			
Do	28	18	19		Dug, 6 by 8 feet	20	14		Hand	S			
L. Ballou	14	19	17	1890	Bored, 8 inches	140	138		Wind, horse	N			
Eugene Cosgriff	4	20	17		Bored, 7 inches	160	140		Horse	S		300	
E. B. Martin	6	20	17	1889	Bored, 8 inches	160	140		Wind, horse				
Pleasant Valley Stock Farm	32	20	16		Bored, 7 inches		0	68	Artesian	I	9		
Do	32	20	16		Bored, 12 inches		0	68	....do	I	2		
Do	32	20	16		Bored, 7 inches		0	68	....do	I	[a] 5		
Do	32	20	16		Bored, 12 inches		0	68	....do	I			
Coalinga Consolidated Water Co	16	20	15	1898	[b]	275-300	230	76	Steam	B	[a] 18		
Valley Water Co.[c]	12	20	14	1901	Bored, 6 inches	300	150	76	....do	B	[a] 10		
J. A. McClurg	35	20	14		Bored, 8 inches	720	0		Artesian	D	1		
Bunting Iron Works	32	20	15	1905	Bored, 7⅛ inches	255	110		Steam	D, S	3		
Do	32	20	15	1905	Bored, 12 inches	268	110		....do	D, S			
J. R. Baird	1	21	16	1901	[d]	18-56	0		Artesian	D, I	[a] 25		
W. J. McFee	30	20	17		Bored, 7 inches		210		Not raised	N			
Joseph Mouren	11	20	17	1890	....do	150	130	73	Wind	S			
W. J. Dickey	8	20	18	1890	Bored, 8 inches	180	140?		....do	N			
	28	19	19	1889	Bored, 6 inches	1,100	0		Artesian	S	Small.		
Marion Heinlen	5	19	20		....do	500	0	76	....do	S	3		
Do	5	19	20		Bored, 5 inches	100	0	71	....do	S	Small.		
Antone Neunes	22	18	20	1902	Bored, 2 inches	128	0		....do	D, S	Small.		
A. A. DeGroat	22	18	20	1903	Hydraulic, 2 inches	140	0	70	....do	D, S	Small.		
Thomas Fanucken	32	18	20	1900	Bored, 5 inches	105	0	70	....do	D	Small.		
Mary Taylor	32	18	20	1899	....do	100	0	70	Artesian, hand	D, S	Small.		
A. K. Taylor[c]	32	18	20	1899	....do	130	0	69	Artesian	D, S	Small.		
R. A. Morrison	33	18	20	1904	....do	138	0		....do	D, S	Small.		
J. A. Green	32	18	20	1896	....do	96	0	70	Artesian, hand	D, S	Small.	85	
Rhodes estate	28	18	20	1889	Bored, 8 inches	700	0	76	Artesian	I, S	[a] 20		
Manuel Perera	29	18	20		Bored, 2 inches	120	8		Wind	D, S			
Frank Sharpels	16	18	20	1898	Bored, 5 inches	170	10		Hand	D			4.00
J. Sutherland	28	18	20	1894	Bored, 2 inches	530	0		Artesian	D, S	Small.		
J. D. Patterson	22	18	20	1892	Bored, 5 inches	106	3		Hand	D		99	
W. A. Long	18	18	21		....do	33	6		....do	D, S		16	4.00
J. Sutherland	15	18	20	1899	....do	96	3		....do	D, S		65	3.00
C. H. Smith	32	17	21	1897	....do	30	10		....do	D, S			4.50
R. V. Daggett	4	18	21	1880	Bored, 6 inches	40	10		....do	D, S			2.25
P. C. Phillips	28	17	21	1899	Bored, 5 inches	48	13.5		....do	D			6.00
Judson Stutson	6	13	19	1883	Bored, 7 inches	115	60		Wind	D, S			
Southern Pacific Co	5	12	19	1887	Dug, 12 feet; bored, 8 inches.	140	85		Steam	B			
E. J. Bullard	31	12	20	1886	Bored, 8 inches		70		Wind	D, S			
Do	5	13	20		....do		100		....do	D, S			
J. H. Funck	3	13	20	1892	Bored, 7 inches	80	32		Hand	D			
J. H. Randel	34	12	20		Bored, 6 inches	70	60		Horse	D, S			
E. J. Lane	22	12	20	1894	Bored, 8 inches	99	85		Wind	D, S		145	41.00
J. P. Williams	14	12	20		Bored, 6 inches	115	90		....do	D, S			
A. B. Ball	7	12	21	1892	....do	145	80		....do	D, S			
Milo Rowell	5	12	21	1880	Bored, 7 inches	130	60		....do	D			174.00
V. B. Cobb	9	12	21		Dug	47+	33		Hand	D, S			

[a] Yield estimated or statement of owner taken.
[b] Two wells, 7⅛ inches; one well, 9⅛ inches; and one well, 11⅛ inches diameter.
[c] Two wells.
[d] Four 6-inch and four 8-inch wells.

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TABLE XV

Owner.	Location		Year planted.	Diameter and Circumference of Trunk.	Height of Trunk.	Height to Branches.	Spread of Branches.	Material of Fills.	Area of Ground Covered.	Number of Trees.	Value of Trees.
J. M. Heskell	22	21	1870	Diam. 6 inches.	10ft.	8ft.	8ft.	Wood	1	1	$
Fresno National Bank	22	21	1870	Diam. 8 inches.	10ft.	8ft.	8ft.	Iron	1	1	$
T. P. Nelson	22	21	1870	Diam. 6 inches.	10ft.	8ft.	8ft.	Wood	1	1	$
J. E. Dickerson	22	21	1870	Diam. 6 inches.	10ft.	8ft.	8ft.	Wood	1	1	$
J. B. Collins	22	21	1870	Diam. 6 inches.	10ft.	8ft.	8ft.	Wood	1	1	$
Jack Simpson	22	22	1870	Diam. 6 inches.	10ft.	8ft.	8ft.	Wood	1	1	$
Marvin Simpson	22	22	1870	Diam. 6 inches.	10ft.	8ft.	8ft.	Wood	1	1	$
D. C. Sample	22	22	1870	Diam. 6 inches.	10ft.	8ft.	8ft.	Wood	1	1	$
Do.	22	22	1870	Diam. 6 inches.	10ft.	8ft.	8ft.	Wood	1	1	$
J. W. Potter	22	21	1870	Diam. 6 inches.	10ft.	8ft.	8ft.	Wood	1	1	$
Do.	22	21	1870	Diam. 6 inches.	10ft.	8ft.	8ft.	Wood	1	1	$
A. Henderson	22	21	1870	Diam. 6 inches.	10ft.	8ft.	8ft.	Wood	1	1	$
H. B. Bissell	22	21	1870	Diam. 6 inches.	10ft.	8ft.	8ft.	Wood	1	1	$
F. E. Brown	22	21	1870	Diam. 6 inches.	10ft.	8ft.	8ft.	Wood	1	1	$
J. W. Brown	22	21	1870	Diam. 6 inches.	10ft.	8ft.	8ft.	Wood	1	1	$
Gudlip Ambrosia	22	21	1870	Diam. 6 inches.	10ft.	8ft.	8ft.	Wood	1	1	$
Harry Maupin	22	21	1870	Diam. 6 inches.	10ft.	8ft.	8ft.	Wood	1	1	$
Chas. A. Owens	22	21	1870	Diam. 6 inches.	10ft.	8ft.	8ft.	Wood	1	1	$
Gus Ploets	22	21	1870	Diam. 6 inches.	10ft.	8ft.	8ft.	Wood	1	1	$
H. V. Parker	22	21	1870	Diam. 6 inches.	10ft.	8ft.	8ft.	Wood	1	1	$
J. Walker	22	21	1870	Diam. 6 inches.	10ft.	8ft.	8ft.	Wood	1	1	$
California Bank	22	21	1870	Diam. 6 inches.	10ft.	8ft.	8ft.	Wood	1	1	$
Do.	22	21	1870	Diam. 6 inches.	10ft.	8ft.	8ft.	Wood	1	1	$
Mrs. Thornton	22	21	1870	Diam. 6 inches.	10ft.	8ft.	8ft.	Wood	1	1	$
California Bank	22	21	1870	Diam. 6 inches.	10ft.	8ft.	8ft.	Wood	1	1	$
Kennedy & Owen	22	21	1870	Diam. 6 inches.	10ft.	8ft.	8ft.	Wood	1	1	$
Mr. Williams	22	21	1870	Diam. 6 inches.	10ft.	8ft.	8ft.	Wood	1	1	$
Lafayette Pearson	22	21	1870	Diam. 6 inches.	10ft.	8ft.	8ft.	Wood	1	1	$
Balfour Guthrie & Co.	22	21	1870	Diam. 6 inches.	10ft.	8ft.	8ft.	Wood	1	1	$
Mrs. E. G. McGardle	22	21	1870	Diam. 6 inches.	10ft.	8ft.	8ft.	Wood	1	1	$
E. E. Ward	22	21	1870	Diam. 6 inches.	10ft.	8ft.	8ft.	Wood	1	1	$
B. T. Tipton	22	21	1870	Diam. 6 inches.	10ft.	8ft.	8ft.	Wood	1	1	$
J. Mills	22	21	1870	Diam. 6 inches.	10ft.	8ft.	8ft.	Wood	1	1	$

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M. Dunlavey	33	13	20	1895	do	90	7	do	D				
C. D. Edgerly	27	13	20	1890	Bored, 2½ inches	85	10	Wind	D				25.00
Mr. Bailey	28	13	20	1896	Bored, 2 inches	55	9	Hand	D				
	21	13	20		Bored, 6 inches		17	Wind	D				
T. C. White	22	13	20		Bored, 7 inches	50	18	do	D				
Wm. Bitner	14	13	20		Bored, 2½ inches		15	Hand	D				5.00
F. M. Merrit	14	13	20		Bored, 7 inches	+100	13	Wind	D, S				
Paul Leonhart	19	13	21	1889	Bored, 1¼ inches	70	9	Hand	D		80		5.00
Olsen estate	19	13	21	1899	Bored, 6 inches	80	7	Steam, wind	W, D		100		
F. M. Roessler	30	13	21	1890	Bored, 2 inches	50	6	Wind	D				
Eggars estate					Bored, 8 inches		6	Steam	W, D	2			
P. H. McGarry	21	13	21	1891	Bored, 5 inches	80	6	Hand	D		40		
M. F. Tarpey	21	13	21		Bored, 2 inches	110	7	Wind	D, S		33		
Andrew Palm	15	13	21	1891	do	85	6	Hand	D		25		5.00
J. W. Sharer	15	13	21	1890	Bored, 6 inches	80	9	do	D, S				
R. T. Owen	8	13	21	1881	Bored, 7 inches	90	13	Wind	D				
C. R. Damon	8	13	21	1898	Bored, 5 inches	54	10	Hand	D, S		175		18.00
Cates estate	2	13	21	1894	Bored, 7 inches	40	10	Wind	D, S				5.00
J. D. Reyburn	11	13	21	1892	do	85	12	do	D, S		85		125.00
E. E. Irwin	14	13	21	1885	Bored, 8 inches	85	9	do	D, S				65.00
R. G. Hewitt	14	13	21	1892	Bored, 2 inches	90	12	Hand	D, S				85.00
A. J. Cass	14	13	21	1891	do	60	9	do	D		$30		8.00
L. M. Fincher	22	13	21	1880	Bored, 8 inches	75	6	do	S				6.00
Mr. Herman	24	13	21	1897	Bored, 2 inches	40	8	do	D, S		12		6.00
McDonald estate	18	13	22	1877	Dug	80	15	do	D, S				
Sam Ebe	8	13	22		do		11.5	do	D				
Sacramento Bank	8	13	22	1880	do	60	22	Wind	D				
B. F. Griffen	6	13	22	1880	do	50	28	do	D				40.00
Fresno Loan & Savings Bank	6	13	22	1882	do	37	18	do	D, S				14.00
T. C. White	9	13	22	1882	Bored, 8 inches	75	35	Hand	D				6.00
W. M. Harbison	10	13	22	1882	Bored, 6 inches	82	37	Wind	D, S				90.00
John Lee estate	19	13	22	1880	do	60	23	do	D, S				40.00
Alfred Beard	15	13	22	1885	Bored, 8 inches	75	38	do	D, S				35.00
John Snyder	35	13	22	1897	Bored, 7 inches	65	20	Hand	D, S		20		4.00
Chas. Lyman estate	34	13	22	1880	do	80	0	do	D				4.00
John Crol	9	14	22	1892	Bored, 6 inches	50	17	do	D, S		55		4.00
Dr. Chester Rowl	4	14	22	1897	Bored, 2 inches	95	14	do	D, S				
Sacramento Bank	6	14	22		Bored, 5 inches		9	do	D, S				4.25
R. B. Baird	32	13	22	1900	Bored, 2 inches	75	11	do	D, S		20		6.00
M. E. Laymensce	36	13	21	1891	do	60	8	do	D, S				
Cora Wickersham	3	14	22	1890	Bored, 7 inches		14	Wind	D, S				
Judge Wallace	35	13	21	1899	Bored, 2 inches	45	20	Hand	D		23		5.00
Judge Risley	6	14	22	1893	do	90	18	do	D, S		25		4.00
Bonner Vineyard Co	11	14	21	1885	Bored, 8 inches	104	14	Horse	D, S		100		100.00
Fred Roeding	2	14	21	1887	Bored, 7 inches	110	17	Wind	D				
S. E. Mill	34	13	21	1899	Bored, 2 inches	70	12	do	D, S		23		46.00
Alice Treadwell	34	13	21	1887	do	85	10	Hand	D		40		4.00
W. F. Carrico	33	13	21	1885	Bored, 5 inches	78	9	do	D, S				4.50
C. D. Wright	5	14	21	1896	Bored, 2 inches	80	8	do	D				4.00
St. George Winery	5	14	21	1894	Bored, 10 inches	300	6	Steam	W	10	120		
Hughs Richler	6	14	21	1880	Bored, 2 inches	40	10	Hand	D, S		16		4.25
H. M. Rustigian	6	14	21	1891	do	60	12	do	D, S		25		4.00

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TABLE 52.—*Records of wells in Fresno County*—Continued.

Owner.	Location.			Year completed.	Type and diameter of well.	Depth of well.	Depth to water level.	Temperature of water.	Method of lift.	Use of water.	Yield.	Cost of well.	Cost of machinery.
	Section.	Township south.	Range east.										
						Feet.	*Feet.*	*°F.*			*Miner's inches.*		
J. M. Ellmore	15	13	22	1884	Bored, 8 inches	80	37	.....	Wind	D, S	.....	$80	$165.00
D. J. Dickey	25	13	20	1892	Bored, 7 inches	120	7	.....	Gas, hand	D	.....	.....	.....
G. T. Hawley & Bro	25	13	20	1895	Bored, 2 inches	90	15	.....	Hand	D, S	.....	.....	4.00
Mr. Hayes	25	13	20	1882	Bored, 7 inches	70	11	.....	do	D, S	.....	.....	6.00
A. Vogel	34	13	20	1888	Bored, 4 inches	60	8	.....	Wind	D, S	.....	.....	.....
John D. Rutledge	4	14	20	1897	Bored, 2 inches	75	6	.....	Hand	D	.....	16	4.00
T. L. Hunter	4	14	20	1898	Bored, 7 inches	55	5	.....	do	D	.....	.....	.....
August Weihe	5	14	20	1897	Bored, 2 inches	35	7	.....	do	D, S	.....	8	3.50
Geo. Roeding	31	14	20	1900	Bored, 5 inches	93	12	.....	Wind	D, S	.....	73	50.00
Balfour Guthrie & Co	36	13	19	1880	do	30	17.5	.....	do	D, S	.....	.....	4.00
	35	13	19	.....	Bored, 2 inches	.....	9	.....	do	D, S	.....	.....	4.00
C. D. Smith	2	14	19	1890	Bored, 3 inches	70	5	.....	do	D, S	.....	42	50.00
I. C. Barman	18	14	19	1893	Bored, 1½ inches	85	6	.....	Hand	D, S	.....	.....	3.50
Mat Asmussen	12	14	18	1881	Bored, 2 inches	70	8	.....	do	D, S	.....	21	3.25
	26	14	18	.....	do	21	9	.....		D, S	.....	.....	.....
Geo. P. Thornton	30	14	19	1893	do	80	8	.....	Wind	D, S	.....	24	47.00
Mrs. G. F. Thornton	29	14	19	1893	do	90	10	.....	do	D, S	.....	25	89.00
T. H. Burgess	15	14	19	1898	do	90	8	.....	do	D, S	.....	29	41.00
Herman Boyce	23	14	19	.....	do	.....	8	.....	Hand	D, S	.....	.....	4.00
August Weye	27	14	19	1881	Bored, 6 inches	+80	7	.....	Horse, wind	D, S	.....	60	120.00
Burley Bros	27	14	19	1887	Bored, 7 inches	65	8	.....	Wind	D, S	.....	43	60.00
F. Duhring	34	14	19	1887	Bored, 6 inches	.....	8	.....	Hand	D	.....	.....	4.00
R. L. Epperson	36	14	19	1894	Bored, 2 inches	60	8	.....	do	D	.....	24	4.00
R. L. Dunham	36	14	19	1900	do	44	8	.....	do	D, S	.....	19	4.00
Mr. Parker	25	14	19	1898	do	70	6	.....	do	D, S	.....	.....	4.00
J. J. Luce	12	14	19	1896	do	72	8	.....	do	D, S	.....	.....	.....
Mrs. C. B. Lyman	1	14	19	1900	Bored, 6 inches	97	9	.....	Wind	D, S	.....	60	270.00
Victor Martin	9	14	20	1897	Bored, 2 inches	82	10	.....	do	D	.....	.....	200.00
L. A. Gould	26	14	20	1890	do	80	7	.....	do	D, S	.....	40	150.00
H. H. Hass	16	14	20	1890	do	70	8	.....	do	D, S	.....	.....	.....
O. D. Garrison	21	14	20	1888	do	120	8	.....	do	D	.....	48	4.25
T. H. Mallory	21	14	20	1900	do	69	10	.....	do	D	.....	28	300.00
E. Tommasini	29	14	20	1897	do	82	12	.....	Hand	D, S	.....	.....	26.00
M. Robison	32	14	20	1890	do	70	10	.....	do	D, S	.....	.....	3.00
G. C. Cheuvraut	33	14	20	1892	do	75	6	.....	do	D, S	.....	25	4.00
Richard White	33	14	20	1884	Bored, 8 inches	52	6	.....	do	D, S	.....	52	4.00
H. Roff	33	14	20	1880	do	90	9	.....		D, S	.....	80	.....
W. A. White	27	14	20	1900	Bored, 2 inches	57	10	.....	Wind	D, S	.....	225	45.00

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E. F. Ball	14	14	20	1893	Bored, 6 inches	35	13		do	D, S				
Fresno Loan & Savings Bank	14	14	20	1880	do	65	8		do	D, S			65	
Estrella de Ora Drying Co	13	14	20	1891	Bored, 2 inches	75	5		Hand	D				
F. G. J. Schmidt	23	14	20	1886	do	40	10		do	D, S			20	3.25
Geo. A. Coughell	34	14	20	1885	do	+40	8		do	D, S				4.00
Henry Brooks	3	15	20	1885	do	80			do	D, S			32	4.00
Robert Boot	2	15	20	1880	Bored, 6 inches	90	12		do	D, S			90	4.00
Fresno National Bank	36	14	20	1890	Bored, 2 inches	24	8		Wind	D, S			37	72.00
	1	15	30		Bored, 6 inches		10.5		Hand	D, S				4.00
E. R. Bates	19	14	21	1890	Bored, 2 inches	82	10		Wind	D, S				250.00
Edwin Bullock	25	14	20	1899	Bored	70	12		do	D, S				35.00
Mrs. F. C. Ketchum	13	14	20	1890	Bored, 2 inches	60	12		Hand	D, S			24	4.00
R. J. Robinson	3	14	20	1900	do	73	10		do	D			29	4.25
Mr. Meyers	2	14	20	1890	do	30	15		do	D, S			15	4.25
Fresno County	2	14	20	1897	Bored, 7 inches		10		Gas	R		24		
D. J. Vaughn	12	14	20	1882	Bored, 5 inches	65	9		Wind	D			45	9.00
Fresno Vineyard Co	7	14	21		Bored, 6 inches		9		Gas	D				
M. E. Sherman	17	14	21	1899	do	40	10		Steam	I		100	206	1,300.00
Do	17	14	21	1899	do	120	10							
C. N. Brenenfeld	20	14	21	1895	Bored, 2 inches	80	9		Hand	D, S			25	5.00
James Rutherford	21	14	21	1891	do	100	9		do	D			40	3.00
J. W. Scott	29	14	21	1897	do	60	7		do	D, S			24	3.00
J. H. Larue	32	14	21	1886	Bored, 5 inches	50	8		Wind	D, S			40	75.00
A. A. Smith	32	14	21	1890	Bored, 2 inches		12		Steam	D				
H. M. Eddy	33	14	21	1887	do	65	9		Hand	D, S			65	25.00
Lone Star school district	22	14	21	1897	do	60	12		do	D, S			24	4.00
M. Wash	27	14	21		Bored, 5 inches		13		do	D, S				4.00
W. H. Martin	26	14	21	1890	Bored, 2 inches		14		Hand	D, S				3.25
Mrs. J. J. Owen	31	14	22	1898	Bored, 5 inches	48	13		Wind	D, S			26	
D. W. Butler	31	14	22	1898	do	60	11.5		Hand	D, S			23	3.25
S. A. Tyler	32	14	22	1900	Bored, 8 inches	75	15		Wind	D, S				
Siering Bros	13	14	21	1892	Bored, 5 inches	90	10		do	D, S			90	65.00
Charles Preuss	19	14	22	1892	do	38	12		Hand	D, S			19	
W. H. Spitler	22	14	22		do	25	16		do	D, S				
W. R. Wilson	21	14	22		do		18		do	D, S				3.25
Will McKenzie	28	14	22		Bored, 2 inches	54	12		do	D, S				3.00
J. A. Roberts	3	15	22	1892	Bored, 6 inches	85	14		do	D, S				3.00
H. White	27	14	22	1892	Bored, 2 inches	32	10		do	D, S			4	3.50
S. W. Lewis	14	14	22	1898	Bored, 12 inches	48	18		Wind	D, S				
Mrs. J. D. Reese	9	14	23	1899	Dug	18	14		Hand	D, S				12.00
L. W. Hobler	14	14	23	1894	Bored, 2½ inches	14	10		do	D			10	
Jake Eppinger	26	14	23	1897	Bored, 6 inches	90	27		Wind	D, S				
Alta school district	30	14	24		Bored, 5 inches	100	20		Hand	D, S				4.25
Mrs. Merrit	29	14	24	1885	Bored, 6 inches	40	20		Wind	D, S				
Mr. Martinez	33	14	24	1896	Bored, 5 inches	97	12		Hand	D, S			97	3.25
Victor Franzen	12	15	23	1881	do	60	32		Wind	D, S				
Sacramento Bank	6	15	24		Bored, 7 inches	30	12		Hand	D, S				4.00
Gosliner Bros	7	15	24	1885	do	80	25		Wind	D, S			80	
German Loan & Savings Bank	13	15	23	1886	Bored, 5 inches	58	22		do	S				
A. L. Holmes	24	15	23		do	38	29		Hand	D, S				5.00
R. M. Wilson	19	15	24	1891	Bored, 7 inches	64	15		Wind	D, S				
California Flume & Lumber Co	29	15	24		Bored, 5 inches	50	13		Hand	D				3.50

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TABLE 52.—*Records of wells in Fresno County*—Continued.

Owner.	Location. Section.	Township south.	Range east.	Year completed.	Type and diameter of well.	Depth of well.	Depth to water level.	Temperature of water.	Method of lift.	Use of water.	Yield.	Cost of well.	Cost of machinery.
						Feet.	*Feet.*	°*F.*			*Miner's inches.*		
L. Pederson	33	15	24	1900	Bored, 5 inches	75	12	.....	Hand	D, S	.....	$30	$3.50
Burris Bros.	26	15	23	.....	do	23	21	.....	do	D, S	.....	.....	4.25
Joe Housley	27	15	23	1830	Bored, 6 inches	71	35	.....	Wind	D	.....	.....	.....
Mr. Fisher	14	15	23	.....	Bored, 5 inches	80	35	.....	do	D, S	.....	.....	.....
Fink school district	10	15	23	1900	do	100	42	.....	Hand	D, S	.....	.....	.....
J. H. Harden	15	15	23	1885	Bored, 6 inches	84	50	.....	Wind	D, S	.....	84	100.00
T. L. Reed	22	15	23	1889	Bored, 5 inches	.....	60	.....	Hand	D, S	.....	.....	.....
Southern Pacific Co.	8	15	23	.....	do	.....	30	.....	do	S	.....	.....	.....
Milton M. West	21	15	23	1891	do	45	40	.....	do	D, S	.....	.....	.....
N. Boysen	20	15	23	1891	Bored, 8 inches	55	25	.....	do	D, S	.....	.....	.....
J. M. Marshall	29	15	23	1881	Bored, 6 inches	116	30	.....	Wind	D, S	.....	116	42.00
M. E. Stanton	32	15	23	1888	Bored, 5 inches	62	40	.....	do	D, S	.....	.....	.....
John Holnberg	33	15	23	1889	Bored, 6 inches	93	50	.....	Hand	D, S	.....	.....	.....
G. Stromberg	4	16	23	1899	do	85	30	.....	do	D, S	.....	67	11.00
Heald & Helley	6	16	23	1897	Bored, 5 inches	.....	14	.....	do	D, S	.....	.....	12.00
G. Bordson	6	16	23	1888	do	40	14	.....	Wind	D, S	.....	.....	200.00
Martin Miller	30	15	23	1880	do	70	20	.....	do	D, S	.....	70	46.00
Sacramento Bank	19	15	23	1885	do	53	30	.....	Hand	D, S	.....	53	11.00
C. O. Love	18	15	23	1885	Bored, 6 inches	30	25	.....	do	D, S	.....	.....	5.00
E. L. Jediker	13	15	22	1884	Bored, 5 inches	59	25	.....	Wind	D, S	.....	59	158.00
Kimble estate	7	15	23	.....	Bored, 6 inches	60	35	.....	do	D, S	.....	.....	.....
H. O. Marshall	11	15	22	.....	Bored, 5 inches	.....	14	.....	Hand	D, S	.....	.....	3.50
H. S. Hulbert	9	15	22	1879	do	72	10	.....	Wind	D, S	.....	79	200.00
A. J. Wells	9	15	22	1883	do	52	12	.....	Hand	D, S	.....	30	3.00
Shafer Bros.	14	15	22	1886	do	70	16	.....	do	S	.....	.....	3.50
G. L. Traber	26	15	22	1877	do	60	15	.....	do	D, S	.....	.....	3.50
H. F. Graper	2	16	22	1888	Bored, 6 inches	48	13	.....	do	D, S	.....	36	3.50
	27	15	22	.....	Bored	.....	16.5	.....	do	D, S	.....	.....	.....
D. C. McClarly	27	15	22	1881	Bored, 6 inches	65	15	.....	do	D, S	.....	.....	3.25
F. P. Wall	22	15	22	1894	Bored, 1½ inches	60	17	.....	do	D, S	.....	.....	.....
Charles Woods	9	15	22	1885	Bored, 5 inches	.....	13	.....	do	D, S	.....	.....	4.00
A. T. Wilkinson	5	15	22	1889	Bored, 1½ inches	30	18	.....	Wind	D, S	.....	15	40.00
A. D. Wilson	12	15	21	.....	Bored, 5 inches	.....	11	.....	do	D, S	.....	.....	.....
F. Lemon	13	15	21	.....	do	.....	13	.....	Hand	D, S	.....	.....	.....
T. M. Boyd	17	15	22	1881	do	60	13	.....	do	D, S	.....	60	11.00
George West & Son	29	15	22	1900	Bored, 8 inches	120	16	.....	Steam	W	10	132	.....
Mrs. L. Vance	31	15	22	1895	Bored, 5 inches	75	15.5	.....	Hand	D, S	.....	.....	3.25
C. T. Pierson	6	16	22	1890	Bored, 2 inches	80	12	.....	do	D, S	.....	.....	2.25

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S. Y. Gordon	7	16	22	1882	Bored, 5 inches	108	10		do	D, S		88	12.00
John H. Hoffman	1	16	21	1894	do	35	12		do	D, S		20	4.00
C. E. Roberts	1	16	21	1888	do	60	14		do	D, S			3.50
Wm. Dosdon	24	15	21	1894	Bored, 2 inches	60	15		Wind	D, S		27	40.00
J. M. Pugh	11	15	21	1882	Bored, 5 inches	42	12		do	D		26	14.00
Wylie M. Giffen	2	15	21		do		12.5		Hand	D, S			5.00
H. A. Ross	2	15	21	1898	do	60	12		do	D, S		45	4.00
R. F. Oliver	3	15	21	1899	do	29	16		do	D, S		21	4.00
A. R. Brown	10	15	21	1900	do	54	12		Wind	D, S		30	
W. R. Shannon	14	15	21	1890	do	52	11		Hand	D, S		26	11.00
Lem Lhung	15	15	21	1899	Bored	90	15		Wind	D			
A. Harris	23	15	21	1881	Bored, 5 inches	+100	14		Hand	D, S		75	11.00
J. C. Long	28	15	21	1892	Bored	80	12		Wind	D, S		60	100.00
Mrs. C. E. Gower	27	15	21	1894	Bored, 5 inches	85	14		do	D, S		75	
M. Leeper	34	15	21	1887	Bored, 2 inches	60	14		do	D		40	117.50
W. J. Zimmerman	34	15	21	1899	Bored, 6 inches	28	12		Hand	D, S		17	3.25
Fresno Loan & Savings Bank	34	15	21	1888	Bored, 5 inches	+100	12		do	D, S			3.25
J. B. Galbreath	28	15	21		Bored, 6 inches		14		Wind	D, S			
T. E. Finerty	4	16	21	1885	Bored, 5 inches	80	16		do	D, S		80	4.25
H. C. Hinkle	11	16	21	1890	do	40	8			D, S			
H. Craben	9	16	21	1894	do	50	14		Hand	D, S		25	3.25
Robert E. Hall	4	16	21	1890	do	100	14		Wind	D, S			49.00
Mr. Madden	29	15	21	1885	do	100	12		do	D, S			70.00
John K. Kennedy	30	15	21	1894	do	96	13		Hand	D, S		57	3.25
W. A. Mills	16	15	21	1900	do	48	14		do	D, S		30	4.00
S. U. Goree	8	15	21	1891	Bored, 4 inches	60	10		do	D, S		24	4.00
J. V. Lamore	18	15	21	1885	Bored, 2 inches	60	12		do	D, S		25	3.25
Chas. K. Kirby	18	15	21	1882	Bored, 5 inches		12		Wind	D, S			
J. F. Ward	12	15	20	1888	Bored, 2 inches	90	8		Hand	D, S		36	4.00
J. B. Perrin	12	15	20	1882	Bored, 5 inches	22	13		Wind	D, S		45	45.00
A. Buckland	11	15	20	1881	do	51	8		Hand	D, S		46	4.00
Phillip Koekler	26	15	20	1897	Bored, 2 inches	60	12		do	D, S		25	
Harland & Stevens	31	15	21	1885	Bored, 5 inches		14		do	D, S			4.00
E. R. Haycroft	6	16	21		Bored, 6 inches	50	12		do	D, S		62	4.00
C. M. Rasmussen	6	16	21	1885			12		do	D, S			4.00
C. Nelson	26	15	20		Bored, 2 inches	54	12		do	D, S		22	4.00
G. A. Pell	26	15	20	1890	do	60	12		Wind	D, S		24	47.00
Stevens & Harland	3	16	20		Bored, 5 inches	+ 50	15		do	D, S			
Do	3	15	20		do	+ 50	16		Hand	D, S			4.00
John Smith	21	15	20	1890	Bored, 2 inches	35	10		do	D, S		15	6.00
Mr. Dickerson	9	15	20	1885	do		10		do	D, S			4.00
N. M. Nelson	10	15	20		do	75	10		do	D, S			4.00
Geo. B. Rowell	3	15	20	1881	Bored, 8 inches	94	10		Wind	D, S		94	
J. Gowanlock	8	15	20	1890	Bored, 2 inches	*60	10		Hand	D, S		25	4.00
D. W. Smith	31	15	20	1887	Bored, 7 inches	80	12		Gas			100	
A. B. Trautwein	6	16	20	1891	Bored, 2 inches	150	12		Wind	D, S			35.00
Louis Montego	1	16	19		Bored, 5 inches	+50	17			D, S			
S. F. Bank	36	15	19		Bored, 6 inches	36	10						
John Rottger	13	16	19		Bored, 3 inches		8		Hand	D, S			4.00
A. Christian	10	15	19	1890	Bored, 2 inches	100	9		Wind	D, S		40	95.00
J. W. Creelman	10	15	19	1890	Bored, 6 inches		10		Hand	D, S			
Geo. Keslang	14	15	19	1891	Bored, 2 inches	65	10		do	D, S		25	4.00

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TABLE 32. *Records of wells in Fresno County*—Continued

Owner.	Location. Section.	Township S., R. E. or W.	Range E. or W.	Year completed.	Type and diameter of well.	Depth of well.	Depth to water level.	Head of water.	Method of lift.	Use of water.	Yield.	Cost of well.	Cost of lift and delivery.
						Feet.	Feet.	Feet.			Miner's inches.		
San Francisco Bank	7	16	20	1888	Bored, 7 inches	130	80		Wind				
G. Kowser	20	16	20		Bored, 5 inches	48	17		Hand				$4 00
Captain Cuttle	30	16	19	1880	Bored	75	14		Wind				
Mrs. H. Worswick	1	17	19	1890	Bored, 6 inches	68	10		Hand			$60	4 00
Mrs. M. J. Hatch	34	16	19	1890	Bored, 5 inches	48	16		Wind				
Fred Eaton	34	16	19	1892	do	72	15		do			40	
Mrs. W. Jenkins	34	16	19	1886	Bored	180	14		Hand				4 00
Elkhorn school district	10	17	19	1890	Bored, 6 inches	100	9		do				
Louis Gobbi	13	17	19	1892	Bored, 6 inches	90	7		do			4	4 00
John Walker	7	17	20	1888	Bored, 8 inches	75	8		do				4 00
Elisha Harlon	18	17	20	1890	Bored, 7 inches	70	8		Wind				10 00
Fred Coleman	8	17	20	1893	Bored, 6 inches	97	7		do				10 00
Lewis Gibbons	6	17	20	1890	Bored, 5 inches	118	10		do				10 00
Loan and Savings Bank	4	17	20	1895	Bored, 6 inches	104	10		Hand				10 00
Chas. S. Pierce	31	16	20	1890	do	45	12		Wind				
David Crawford	33	16	20	1887	do	80	11		do				4 00
Mr. White	16	16	20		do	94	16		Hand				4 00
Wm. Gibson	24	16	20	1890	do	95	12		do			35	4 00
J. H. Hudson	25	16	20	1890	Bored, 5 inches	60	12		do				4 00
Wm. Gibson	31	16	21		do		10		Wind				
J. G. Burnett	30	16	21	1890	Bored, 4 inches	25	7		Hand				4 00
David Helshie	20	16	21	1888	Bored, 5 inches		8, 5		do				
Sacramento Bank	18	16	21	1890	Bored, 6 inches	30	10		do				
Harry Weher	18	16	21		Dug, 1½ feet	18	10		do				
Mr. Johnson	10	16	21		Bored, 5 inches		10		do				
John Reynolds	14	16	21	1892	do	60	9		do				
J. Hamilton	24	16	21	1890	Dug, 2 feet	22	10		do			10	
Dick Butler	22	16	21	1888	Bored, 5 inches	80	11		Wind				
E. R. Holton	28	16	21	1892	do	80	7		Hand				
Lee Burton	28	16	21	1890	Bored, 4 inches	70	10		do			40	
Martin Elder	35	16	21	1898	Bored, 8 inches	52	8		Steam		80	80	400 00
T. J. Martin	26	16	21	1899	Bored, 10 inches	50	8		do		80	45	400 00
Will Pickard	36	16	21	1892	Bored, 5 inches		10		Hand				8 00
C. S. Campbell	24	16	21	1892	do	60	9		Wind				
Sacramento Bank	12	16	21	1890	do	75	12		Hand				8 00
Mrs. C. A. Hammer	18	16	22	1898	do	40	12		do			40	12 00
S. J. Pelton	19	16	22	1898	do	36	10		do				

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J. C. Bell	29	16	22	1880	....do	54	9	.....	Wind	S	.....	50	.....
W. W. Ryce	36	16	21	1886	....do	106	10	.....	Hand	D, S	.....	36	4.00
Sacramento Bank	32	16	22	1875	....do	35	10	.....	....do	D, S	.....	35	4.00
Do	4	17	22	1875	....do	50	10	.....	....do	D	.....	.....	4.00
Larse Anderson	21	16	22	1888	....do	60	21	.....	....do	D, S	.....	30	4.00
C. H. Van Horn	28	16	22	1896	....do	82	12	.....	Wind	D, S	.....	41	.....
Cemetery	27	16	22	.....	....do	.....	13	.....	....do	I	.....	.....	.....
W. T. Prather	17	16	22	1880	Bored, 6 inches	.....	15	.....	....do	D, S	.....	.....	58.00
D. Patton	9	16	22	1880	Bored, 5 inches	100	11	.....	Hand	D, S	.....	.....	.....
T. C. Clayton	3	16	22	1893	....do	102	15	.....	....do	D	.....	51	.....
A. J. Allen	10	16	22	1870	....do	90	16	.....	Wind	D, S	.....	90	60.00
Helge Lee	14	16	22	1896	....do	.....	13	.....	Hand	D, S	.....	.....	3.50
Chas. Strid	23	16	22	1892	....do	30	12	.....	....do	D, S	.....	22	3.50
W. H. Seward	13	16	22	1893	....do	45	15	.....	....do	D, S	.....	35	15.00
Frank Hanson	32	16	22	1889	....do	40	15	.....	....do	D, S	.....	30	3.50
N. J. Shadle	18	16	23	1891	....do	60	20	.....	....do	D, S	.....	44	.....
N. J. Layton	8	16	23	1884	....do	64	20	.....	Wind, hand	D, S	.....	.....	.....
F. C. Stillman	5	17	16	1892	Bored, 7 inches	160	77	.....	Horse	I, S, B	.....	300	.....

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TULARE COUNTY.

GENERAL CONDITIONS.

Tulare County, lying north of Kern and east of Kings, includes the eastern edge of the large central artesian basin at its widest part, all of the delta of Kaweah and Tule rivers and a part of that of Kings River, and the famous citrus region of the foothills and the higher parts of the valley floor about Portersville, Exeter, and Lindsay. It also includes, in the southwestern corner, a part of the old bed of Tulare Lake and a part of the district submerged during the last extremely high water, in 1880. The high water of 1905–1907 did not quite reach the Tulare County line.

Kings, Kaweah, and Tule rivers are the chief sources of such additions to the ground waters as are made in this county, as they are the sources of the surface waters used by the various canal systems.[1] Each of these streams has a distinct though rather flat delta, and the attitude of the ground-water plane indicates that the stream channels and canals along the crests of the deltas are the direct sources of the ground waters in the higher portion of the valley within Tulare County, and that from these lines of supply the waters percolate toward the lower parts of the valley and toward the areas between the deltas. These interareas receive only the slight direct supply that is derived from rainfall and from the minor streams that drain the foothills.

Within the artesian basin south and west of Tulare the ground waters, although receiving local additions within the county, are a part of the general body of ground waters of the central valley, stored there as a result of accumulation from all sources during centuries past, and are in general slow in motion northward along the valley axis.

FLOWING WELLS.

In the 365 or 370 square miles of artesian-water land within the county there were about 125 flowing wells in 1905, representing an investment of between $150,000 and $200,000. Nearly 100 of these wells were used for irrigation, and the combined yield of all of them was estimated at less than 25 second-feet. The greater number of them are 7 inches or more in diameter, while a few old wells are of smaller bore. They are most numerous on the Kaweah delta west of Tulare and somewhat farther south, west of Tipton and Pixley. Pasture lands, alfalfa, gardens, deciduous fruits, and vineyards are irrigated by the use of the waters developed.

[1] An account of these systems was published in U. S. Geol. Survey Water-Supply Papers 17 and 18. These papers are out of print but may be consulted in libraries.

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PUMPING PLANTS.

Irrigation by the use of pumped water is more extensively practiced in Tulare County than anywhere else in the valley. This is due to the development of citrus culture along the foothills between Tule River and Kaweah River, where methods in vogue in the citrus districts south of the Tehachapi have been introduced. There were in all about 170 pumping plants in use for irrigation in 1905, while a number of others were in use for domestic or town supplies. Of the total number 125 were electrically driven by power from one company and 45 were gas or steam plants.

These plants are adapted to a wide variety of conditions, some of them pumping from wells in which the water stands at the surface, and others lifting it from a depth of 100 feet. In the irrigation of some of the hillside citrus groves water is forced to heights of several hundred feet, usually from a reservoir into which it is pumped from the wells. The best equipped plants that overcome lifts of less than 75 or 80 feet use centrifugal pumps directly connected with motors; when the lifts are greater some form of deep-well plunger pump is used.

In the Lindsay district the ground-water level varies greatly each year, falling during the pumping season and rising again in the winter and spring. To keep the pumps and motors within the suction limit during the low-water period, and at the same time to prevent their submersion during the winter season, some of the ranchers have adopted the plan of placing the machinery in a tank. In one plant examined, the motor and pump were fastened to a movable platform that could be raised or lowered in adjustment to the varying ground-water level.

The Badger Irrigation Co. at Exeter has a particularly interesting plant because of the high lift of waters for irrigation. A description of this plant is given in the chapter on pumping tests.

PERMANENCE OF THE GROUND-WATER SUPPLY.

Most artesian basins are very sensitive to development, old wells decreasing in yield as new ones are installed, the shallow wells and those about the upper, outer edge of the basin being the first to show signs of failure. Diminution in the flow of the less favorably situated wells will take place in actual practice long before the basin is overtaxed, hence some alarm is likely to be felt and some individual loss may occur before the alarm is justified by general conditions. In addition to the normal diminution of flow in wells due to physical deterioration in casing or to other causes not related to a general loss of head and reduction in supply, a new well drilled in the neighborhood of an old one, or so situated as to draw in part from the same

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general zone of saturated porous materials, will affect the yield of the first, although the combined yields of the two are much greater than that of either alone and much less than the supply.

Until wells are withdrawing water from an area more rapidly than it is supplied, even though there may be reduction in the yield of individual wells, there is no cause for alarm. It is difficult to determine when this point is reached in an artesian basin because diminution in flowing wells begins soon after development has begun, but when waters are pumped it is less difficult to tell. The continued lowering of the ground-water level in a pumped well, through years of average or abundant rainfall, with gradually increasing lifts and correspondingly increasing costs, indicates overuse.

A comparison of the flows of a number of artesian wells in Tulare County, measured first by the California State Engineering Department in 1885, and 20 years later by the United States Geological Survey, indicates, as is to be expected, a general diminution of yield, this decrease varying from 40 to 90 per cent. A part of it is undoubtedly due to the installation of new wells in recent years, but much of it is to be accounted for by the clogging and filling of the wells and the rusting of the casing. In any event the losses are not serious, and in view of the immensity of the basin and the large supplies that reach it annually, it can not be considered to have approached the point of overuse.

This observation, however, does not hold for some of the areas in which pumping is most intense. The lands favorable for citrus culture are distributed along a frost-free belt on the lower foothills and adjacent high parts of the valley floor. The zone of most intense pumping is along the eastern edge of the valley, between the deltas of Tule and Kaweah rivers. The ground waters here receive some slight accessions from local run-off from the foothills and from minor streams that flow out from them, but their principal source is the constant supply that sinks in the deltas of the major streams and percolates thence slowly in all directions.

On the deltas themselves, especially along their lower portions, where so much damage has been done in recent years as a result of over-irrigation, the consequent rise of the ground-water plane and with it the alkali, pumping is most helpful; in fact, pumping will doubtless be one of the means by which the damage done by over-irrigation in the past will be remedied in the future; but in the citrus belt of Tulare County pumping thus far has been concentrated upon those points remote from the deltas and from the trough of the valley, where supplies are least rapidly replenished. As a result there has been a noticeable lowering of the water plane in recent years and an increased cost of the water product. As a matter of safety to the orchards already producing, means should be taken to prevent the

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A. E. Slaughter	60	...do	...do	...do	Do.
J. J. Mull	35	Low	$Na-CO_3$	Good	Do.
J. H. Hauschildt	11	Moderate	...do	Fair	Fair.
Laurel school district	45	...do	$Ca-CO_3$	...do	Good.
W. A. Bedford	20	...do	$Na-CO_3$	...do	Do.
F. J. Hesse	20	Low	...do	Good	Do.
Mrs. C. Ranger	15	Moderate	...do	...do	Fair.
Pacific Coast Oil Co	25	Low	...do	...do	Good.
J. H. Glide	30	Moderate	$Ca-CO_3$	Poor	Do.
Cutler Bros	35	...do	...do	Fair	Do.
Frank Siseler	35	...do	...do	Poor	Do.
C. M. Midder	25	...do	...do	...do	Do.
M. F. Capell	12	...do	$Na-CO_3$	Fair	Fair.
W. L. Thomas	16	...do	...do	...do	Do.
A. L. Simmons	35	...do	...do	...do	Good.
A. Swanson	80	...do	$Ca-CO_3$	...do	Do.
	4.4	High	Na-Cl	Very bad	Poor.
S. J. Vincent	40	Moderate	$Ca-CO_3$	Poor	Good.
Mr. Leavitt	30	...do	...do	Fair	Do.
H. E. Redman	100	...do	...do	...do	Do.
City of Portersville	70	...do	...do	...do	Do.

Owner.		Classification.			Analyst.
		Chemical character.	Quality for boilers.	Quality for irrigation.	
H. A. Burke	N	Ca-Cl	Bad	Fair	F. M. Eaton.
Southern Pacific Co	M	$Na-CO_3$	Good	Good	Southern Pacific Co.
Do	A	$Ca-CO_3$	Fair	do	Do.
J. H. Hauschildt	N	$Na-CO_3$	Good	Fair	F. M. Eaton.
Tulare Water Co	A	...do	...do	Good	Southern Pacific Co.
Do	N	$Ca-CO_3$	Fair	...do	F. M. Eaton.
Santa Fe Ry. Co	N	...do	...do	...do	Kennicott Water Softener Co.
Southern Pacific Co	M	...do	...do	...do	Southern Pacific Co.
Do	A	...do	...do	...do	Do.
Exeter Waterworks	D	...do	...do	...do	Do.
Mrs. S. Navarre	N	...do	...do	...do	F. M. Eaton.
F. Stone		...do	...do	...do	Do.
G. K. Hostetter		...do	...do	...do	Do.
Southern Pacific Co	Ja	...do	...do	...do	Southern Pacific Co.

foot wells.

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installation of additional pumping plants in those parts of the citrus belt where development is now most intense and the effects upon the ground water have been most clearly discerned, for it is obviously more important to protect the orchards that are already producing than to plant more.

QUALITY OF WATER.

The quality of ground water in the basin of Tulare Lake has been discussed in detail in pages 104–109. Waters from wells 20 to 1,400 feet deep east of the boundary indicated by B'B' (Pl. II), generally are carbonate waters, good or fair for irrigation, containing about 240 parts per million of total solids. Nearly all the deep wells yield sodium carbonate water; nearly all the supplies are low in scale-forming and foaming ingredients and are noncorrosive. The waters from wells less than 100 feet deep show greater difference in quality than the deeper supplies, a condition explainable by the probability that the more highly mineralized ones come from pockets of alkali-impregnated silt. The shallow waters of high mineral content almost invariably are taken from wells on tracts showing alkali.

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WELL RECORDS.

Detailed records of wells in Tulare County that have been examined are assembled in the following tables:

TABLE 55.—*Records of wells in Tulare County.*

Owner.	Location.			Year completed.	Type and diameter of well.	Depth of well.	Depth to water level.	Temperature of water.	Method of lift.	Use of water.	Yield.	Cost of well.	Cost of machinery.
	Section.	Township south.	Range east.										
						Feet.	*Feet.*	°*F.*			*Miner's inches.*		
G. W. Donnel	3	16	23	.....	Bored, 6 inches	70	20	72	Wind	D, S	.....	.....	.....
J. Bollinger	3	16	23	1892	Bored, 5 inches	40	9	71	....do	D	.....	.....	.....
J. O. Kieger	10	16	23	1893	Bored, 6 inches	60	13	68	Hand	D	.....	$30	.....
Mrs. R. Duffy	16	16	23	1903	....do	60	12	71	....do	D	.....	.....	.....
D. H. Dopkins	11	16	23	1883	Bored, 7 inches	46	10	72	....do	D	.....	35	.....
W. P. Moore	13	16	23	1904	Bored, 5 inches	72	9	72	....do	D, S	.....	36	.....
F. Don	7	16	24	1901	....do	75	8	.....	....do	D, S	.....	40	.....
W. C. Lewis	7	16	24	1904	....do	68	6	71	....do	D	.....	35	.....
W. Savatelr	7	16	24	1904	....do	72	8	.....	....do	D	.....	35	.....
G. E. Carver	7	16	24	1904	....do	64	6	72	....do	D, S	.....	30	.....
T. W. Carr	7	16	24	1902	....do	88	7	.....	Wind	D	.....	48	.....
M. E. Hines	1	16	23	.....	....do	85	8	72	....do	D, S	.....	40	.....
J. B. Long	6	16	24	1904	....do	30	7	71	Hand	S	.....	.....	.....
Wm. Anderson	5	16	24	1902	....do	63	7	.....	....do	D	.....	30	.....
G. Botts	5	16	24	.....	Bored, 6 inches	64	8	71	....do	D	.....	.....	.....
E. Finley	9	16	24	.....	Bored, 5 inches	71	8	71	....do	D	.....	.....	.....
W. E. Hawkins	9	16	24	1902	Bored, 6 inches	76	7	72	Wind	D, S	.....	45	.....
W. A. Williams	9	16	24	.....	....do	86	11	72	....do	D, S	.....	50	.....
H. Jacobs	3	16	24	.....	Bored, 5 inches	80	28	71	....do	S	.....	40	.....
B. F. Tout	11	16	24	1885	....do	60	10	70	Hand	D	.....	30	.....
A. McEdminston	11	16	24	1900	....do	60	10	70	....do	D	.....	30	.....
T. Arthur	13	16	24	1901	....do	39	11	72	....do	D	.....	20	.....
N. P. Edmunson	7	16	25	1902	Bored, 10 inches	76	11	.....	Gas	I	46	65	.....
R. S. Demaree	5	16	25	1902	Bored, 12 inches	140	18	.....	....do	.....	.....	120	$600.00
Roy Stevens	5	16	25	1904	Bored, 10 inches	80	13	.....	....do	I	.....	60	560.00
C. W. Steves	5	16	25	1905	....do	75	13	.....	.....	.....	.....	49	.....
H. Bernhorn	8	16	25	1902	Bored, 6 inches	55	11	71	Hand	D	.....	30	.....
J. H. Glide	9	16	25	1883	....do	60	16	71	Wind	D, S	.....	35?	.....
Do	10	16	25	1895	....do	43	15	70	Hand	S	.....	.....	.....
M. W. Curtin	15	16	25	1885	....do	61	15	71	Wind	S	.....	30	.....
J. S. Boyd	22	16	25	1883	Bored, 5 inches	50	13	71	Hand	D, S	.....	25	.....
M. S. Jerryman	28	16	25	1902	Bored, 10 inches	75	11	69	Gas	I	37	75	.....
J. J. Wheelock	27	16	25	1897	Bored, 7 inches	90	11	70	Steam	I	.....	70	.....

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G. W. Kirkman	20	16	25	1890	Bored, 6 inches	36	8	71	Hand	D, S			
T. R. Dennison	20	16	25		Bored, 5 inches	51	8	70	do	D			
A. W. Canfield	13	16	24	1889	do	48	8	70	do	D			
J. T. Ward	24	16	24	1901	Bored, 6 inches	67	8	70	do	D, S		35	
M. A. Haas	14	16	24	1887	Bored, 5 inches	51	8	71	do	D			
Dan Clubb	23	16	24	1903	Bored, 2 inches	65	8	71	do			35	
F. L. Allen	23	16	24	1900	Bored, 5 inches	50	7	71	Wind	D		25	
M. Lyall	23	16	24	1900	Bored, 6 inches	62	8	72	do	D			
A. H. Rohlfin	22	16	24		do	50	10	71		D, S			
C. J. Walker	28	16	24	1901	Bored, 7 inches	35	6	70	Hand	D			
Mrs. J. Vose	21	16	24	1900	Bored, 5 inches	60	6	72	do	D			
Sweet & Levis	28	16	24		Bored, 6 inches	90	6		Wind	S		70	
C. F. Gidding	21	16	24	1900	Bored, 5 inches	60	8	71	Hand	D		20	
A. Frazer	15	16	24	1896	Bored, 6 inches	73	7		Wind	D, S		35	
E. Moore	17	16	24		Bored, 5 inches	75	7	72	do	D, S		40	
L. Lindley	20	16	24		do	70	7	72	do	D, S			
W. I. Rice	19	16	24		do	39	6	70	Hand	D			
C. B. Funk	9	16	24	1904	do	85	7	72	do	D, S		45	
J. F. Miller	20	16	24	1901	Bored, 6 inches	62	7	71	Wind	S		30	
R. F. Dunn	29	16	24		Bored, 5 inches	48	9	71	Hand	D, S		25	
W. L. Heine	14	16	23		do	43	9	72	do	D		20	
A. Scrarone	24	16	23	1897	Bored, 6 inches	68	7		Wind	D, S		35	
R. Kennedy	24	16	23		Bored, 5 inches	36	9		do	S			
Do	26	16	23		Bored, 6 inches	58	10	72	do	D, S			
J. E. Anderson	27	16	23	1893	Bored, 5 inches	52	6	72	do	D, S		40	
W. F. Chrisman	22	16	23	1903	do	54	6	72	Hand	D		30	
G. V. Reed	22	16	23	1897	do		10	68	do	D		15	
J. H. Fox	28	16	23	1890	do	43	7		Wind	S			
M. G. Thompson	27	16	23	1892	do	47	7	72	do	D, S		25	
W. P. Boone	31	16	23	1897	do	48	5	71	do	S		25	
R. H. Fray	4	17	23	1895	Bored, 6 inches	50	5	71	Hand	D		25	
W. Hurse	4	17	23	1905	do	50	5	70	do	D		25	
F. M. Wasgett	23	16	23	1892	Bored, 5 inches	23	4	68	Horse		12	10	
J. A. Boyd	34	16	23	1888	Bored, 6 inches	50	6	70	Wind	D		25	
A. S. Brewer	2	17	23	1890	Bored, 5 inches	43	6	69	do	D, S		20	
D. H. Curtin	35	16	23		do	52	8	72	do	D, S		25	
A. K. Smith	35	16	23	1890	do	35	6	70	do	D, S		20	
Wm. Smith	35	16	23	1897	Bored, 6 inches	26	6	68	Hand	D		15	
California Savings & Loan Society	2	17	23	1890	Bored, 5 inches	30	6	69	do	D		15	
R. Kennedy	36	16	23	1901	Bored, 6 inches	36	5	71	Wind	S		18	
Mrs. E. J. Lovelace	31	16	24		do	50	6	68	Hand	D, S		25	
J. S. Cash	5	17	24	1903	Bored, 5 inches	57	6	70	do	D, S		30	
Mrs. M. Lewis	5	17	24		do	49	4	70	Wind	D, S			
S. K. Green	32	16	24	1889	do	51	4	70	do	D, S		33	
E. C. Tatum	28	16	24	1903	Bored, 6 inches	49	5		do	D, S		25	
S. Hicks	33	16	24	1902	Bored, 5 inches	60	5	69	Hand	D		39	
H. G. Swab	3	17	24	1904	Bored, 6 inches	50	5	70	do	D		25	
R. M. Lewis	34	16	24	1897	Bored, 5 inches	34	4	69	do	D, S		15	
J. W. Garr	34	16	24	1892	Bored, 6 inches	52	5	69	do	D			
S. A. Harris	2	17	24	1904	Bored, 5 inches	35	5	70	do	D		20	
R. J. Kirk	2	17	24	1895	Bored, 4 inches	45	4	67	do	D, S		20	

[a] D, domestic; S, stock; I, irrigation; B, boilers; N, not used.

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TABLE 55.—*Records of wells in Tulare County*—Continued.

Owner.	Location. Section.	Township south.	Range east.	Year completed.	Type and diameter of well.	Depth of well.	Depth to water level.	Temperature of water.	Method of lift.	Use of water.	Yield.	Cost of well.	Cost of machinery.
						Feet.	*Feet.*	°*F.*			*Miner's inches.*		
H. W. Terrill	36	16	24	1902	Bored, 5 inches	60	5	70	Hand	D		$30	
J. H. Glide	31	16	25	1886	Bored, 6 inches	39	9	71	do	D		20	
J. M. Parker	32	16	25	1904	Bored, 2½ inches	65	5		Wind, hand	D, S			
Wm. Kalb	32	16	25	1903	do	60	7		Hand	D, S			
Jacob M. Hamlin	33	16	25	1905	Bored, 5 inches	70	{ 10 / 12 }	70	do	D			
J. G. Hitchcock	3	17	25		Bored, 6 inches	14	7	69	do	D, S			
J. K. Yoakum	35	16	25		Bored, 5 inches	36	15	70	do	D		20	
San Francisco Savings Union	31	16	26		Bored, 6 inches	46	26	70	Wind	D		25	
F. Tessman	5	17	26		do	54	30	70	do	D		25	
Mrs. M. E. Harell	8	17	26		Bored, 5 inches	36	22	69	do	S		20	
Stone Corall school district	12	17	25		do	38	15	69	Hand	D			
Mrs. M. E. Harell	13	17	25		do	48	14	69	do	D, S		25	
J. E. Fentley	22	17	25	1903	Bored, 12 inches	63	11		Gas	I			
J. W. Summers	21	17	25	1884	do	30	8		do	D, S			$110.00
P. Banks	8	17	25	1886	Bored, 5 inches	48	6	68	Hand	D, S			
Cosmos Land & Water Co	29	17	25		Bored, 7 inches	70	12		do	S			
B. Depen	12	17	24	1890	Bored, 6 inches	32	7	69	do	S		15	
W. Sim	24	17	24	1890	Bored, 5 inches	40	6	68	Wind	D, S			
Mrs. E. McCaulley	24	17	24		do	41	6	69	Hand	S		20	
J. Mackin	23	17	24	1889	do	54	5	69	do	D		25	
Sacramento Bank	11	17	24	1902	Bored, 6 inches	44	6	71	Wind	S			
W. Vose	14	17	24	1895	Bored, 5 inches	32	5	68	do	S		15	45.00
D. S. Meyers	10	17	24		do	40	5	68	Hand	N			
H. Williams	15	17	24	1865	Bored, 10 inches	60	6	66	Not raised	N		1	
G. Langrick estate	21	17	24		Bored, 5 inches	30	6	68	Wind	S		15	
J. Harrel Rothmanage	27	17	24		Bored, 6 inches	54	6	66	Hand	D, S			
M. R. Davis	8	17	24		Bored, 5 inches	30	4	65	Wind	S			
A. Murray	18	17	24	1905	Bored	60	5	66	Hand	D		30	
J. A. Kimble	18	17	24		Bored, 6 inches	33	5	70	Wind	D, S		15	
J. A. Moreland	18	17	24		Bored, 5 inches	40	4	70	do	S			
S. Kerr	24	17	23	1902	do	32	4	70	Hand	D, S			
Moreland school district	7	17	23		do	41	4	66	do	D			
J. D. Vannoy	6	17	24	1890	do	56	4	66	Wind	D, S		30	
C. J. Archer	12	17	23		Bored, 6 inches	33	4	65	do	D, S		17	
H. E. Kellog	12	17	23		Bored, 5 inches	38	4	65	Hand	D			
C. W. Clarke	11	17	23		do	54	4	67	do	D			
L. Sproat	10	17	23	1885	do	47	4	67	do	D			

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D. A. Boone	11	17	23	1888	Bored, 6 inches	60	4	69	Wind	D		30	
J. Harris	14	17	23	1889	Bored, 5 inches	56	4	68	....do	D, S		30	
T. Musler	12	17	23		....do	20	4	63	Hand	D		10	
J. A. Mobler	14	17	23	1887	Bored, 6 inches	40	5	71	Wind	D, S		20	
J. W. Alcorn	10	17	23	1886	Bored, 5 inches	29	4	66	Hand	D		15	
J. H. Garlish	10	17	23	1900	....do	27	4	64	....do	D		15	
Traver school district	16	17	23	1890	....do	40	4	66	....do	D		20	
H. Burke	16	17	23	1903	....do	29	5	69	Wind	D		15	
J. Etzenhouser	9	17	23	1893	Bored, 6 inches	60		64	Hand	D		36	
A. T. Hines	8	17	23	1885	Bored, 5 inches	29	5	65	....do	S			
G. Deedle	6	17	23	1890	....do	25	7	66	....do	D		15	
M. Rae	7	17	23	1902	....do	33	5	68	....do	D, S		15	
M. Rodgers	8	17	23		....do	31	4	68	....do	D			
J. H. Jacobs	17	17	23		....do	30	4	69	....do	S		15	
G. Ghemmelspach	21	17	23	1889		16	4	68	....do	D			
A. A. Himrat	20	17	23	1882	Bored, 6 inches	42	5	71	....do	D, S			
C. E. Barlow	30	17	23	1893	Bored, 5 inches	30	7	72	....do	D, S			
C. A. Wood	22	17	23	1885	Bored, 6 inches	31	4	71	....do	D, S		15	
N. Stobie	4	18	24	1900	Bored, 7 inches	60	7	67	Horse	D, S			
H. C. Hartley	25	17	24	1891	Bored, 5 inches	58	5	68	Wind	S		30	
Do	36	17	24		Bored, 7 inches		6	65	Wind, hand	D			
J. Rush	31	17	25		....do	55	5	67	....do	S			
J. G. Hicks	28	17	25	1890	....do	37	9	69	Wind	D, S		40	100.00
R. L. March	28	17	25	1885	Bored, 5 inches	40	8	69	....do	S			
W. H. Keener	34	17	25	1888	....do		6	69	Wind, hand	D, S			
S. Palmer	2	18	25	1887	....do	75	15	70	Wind	D, S			
Ivanhoe school district	6	18	26		Bored, 5 inches	40	14	71	Hand	D			
San Francisco Savings Union	5	18	26		....do	41	20	68	....do	D		20	
J. S. Cox	33	17	26	1900	Bored, 6 inches	23	11	66	....do	D			
	34	17	26	1900	....do	33	11	64	....do	D, S		20	
J. B. Agnew	34	17	26	1880	Bored, 5 inches	25	25		....do	D			
Red Banks Orchard Co.[a]	27	17	26	1903	Bored, 8 inches	60	30	71	Electric	I	23		
H. H. Brown	32	17	27	1903	Bored, 12 inches	100		73	....do	I	[b] 15		
Antelope Heights Water & Irrigation Co	34	17	27	1905	[c]	35	5		Steam	I			
Pogue Bros	11	18	27	1895	Dug	14	57		Electric	D			
E. E. Fitch	5	18	26	1894	Bored, 5 inches	52	19	65	Hand	D		25	
R. C. Hardin	1	18	25	1890	....do	30	16	66	Wind	S			
E. M. Strifler	1	18	25		Dug	15	12	63	Hand	D			
S. G. Uram	12	18	25		Bored, 5 inches	37	12	65	....do	D			
C. Fray	12	18	25	1892	....do	52	10	65	....do	D		25	
L. G. Dickinson	13	18	25	1900	....do	35	11	61	....do	D		20	
T. F. Johnson	2	18	25	1893	Bored, 6 inches	28	6	70	Wind	D, S		15	
J. G. Hicks	3	18	25	1890	Bored, 5 inches	24	6	71	Hand	D		10	
C. Thomas	10	18	25	1885	....do	30	5	66	....do	D			
S. T. Allen	9	18	25		....do	18	8	69	Wind	S			
Sam Ellis	4	18	25	1892	....do	60	5		....do	D, I			
B. F. Kibler	16	18	25		....do	40	5	66	Hand	D			
T. J. Patterson	17	18	25		....do	15	4		Wind	D			
Mrs. G. Chrisman	9	18	25	1900	....do	42	4	67	Hand	D			
J. Watt	8	18	25		....do	30	4	67	....do	D, S			
Morgan Rush	8	18	25		....do	26	6	67	....do	D			

[a] Two wells.

[b] Yield estimated or statement of owner taken.

[c] Two dug wells and three 12-inch bored wells.

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TABLE 55.—*Records of wells in Tulare County*—Continued.

Owner.	Location.			Year completed.	Type and diameter of well.	Depth of well.	Depth to water level.	Temperature of water.	Method of lift.	Use of water.	Yield.	Cost of well.	Cost of machinery.
	Section.	Township south.	Range east.										
						Feet.	*Feet.*	°*F.*			*Miner's inches.*		
Mrs. N. C. Smith	6	18	25	1890	Bored, 10 inches	60	6	66	Wind	D, S			
Howe & Trout	8	18	25	1890	Bored, 6 inches	35	7		Wind, hand	D, I, S			
Seth Smith, jr	7	18	25	1891	Bored, 5 inches		5	64	Wind	D, S			
J. A. Demarer	12	18	24	1886	do	33	3	64	Hand	D			
Cuthbert Burrel estate	12	18	24		Bored, 7 inches	20	2.5		Not raised	N			
A. C. Collier	10	18	24	1903	Bored, 5 inches	62	7	68	Horse	D, S		$32	$25.00
Mr. Crane	12	18	23		do	35	7	69	Wind	D, S			
C. W. Clark	2	18	23	1880	do	42	9	69	Hand	D, S		20	
J. Kame	14	18	23	1880	do	35	9	68	Wind	D, S		15	
Mrs. Codiga	22	18	23		do	38	11	70	do	D, S		20	
W. W. Worthing	22	18	23	1887	do	55	12	70	do	D, S		30	
R. Chatten	26	18	23		do	39	12	71	Hand	S			
E. H. Bock	23	18	23	1897	Bored, 12 inches	50	12		Gas	I	a 122	50	900.00
Edward Landigan	13	18	23	1882	Bored, 6 inches	52	8	70	Hand	D, S		26	4.00
Peter Mallock	18	18	24	1904	Bored, 5 inches	30	20?		Wind	S		15	50.00
Southern Pacific Co	19	18	24		Bored, 8 inches		16?		Steam	B	7		
Bank of Visalia	30	18	24		do	800	0	78	Artesian	I	a 1		
Montgomery estate	29	18	24		Bored, 7 inches	24	10	70	Wind	D, S		20	50.00
Timothy Hayes	17	18	24	1900	Bored, 5 inches	50	12	70	do	D, S		25	25.00
H. S. and H. G. Montgomery	16	18	24		Bored, 8 inches		9	67	Hand	S			4.00
Anna and H. Montgomery	22	18	24		do	33	5		do	S		25	4.00
Arthur Burton	28	18	24	1904	Bored, 6 inches	38	14?	68	do	D, S		19	4.00
G. D. Smith	23	18	24	1902	Bored, 5 inches	24	3	65	do	D, S		12	4.00
Ben Henry	23	18	24	1884	do	60	12?	68	Wind, hand				50.00
T. J. Akers	22	18	24	1901	do	48	13?	65	Wind	D, S		25	50.00
J. B. Jordan	15	18	24	1904	Bored, 6 inches	45	10?	66	Wind, hand	D, S		30	75.00
Mrs. John Parr	23	18	24		do	40	4		Wind	S		20	50.00
J. M. Lasco	23	18	24	1889	Bored, 5 inches	60	4	67	Hand	D, S		35	4.00
C. T. Poole	14	18	24	1902	do	35	5	65	do	D			
Julia Wilcox	23	18	24		do	35	4	64	do	D			
L. Henry	24	18	24	1904	do	30	4	64	do	D			
A. J. Weston	17	18	25	1897	do	45	4		Wind, horse	D, I, S			
Visalia Land & Fruit Co	18	18	25	1905	Bored, 12 inches	95	5		Steam	I			
Togni Rancho	20	18	25	1894	Bored, 5 inches	50?	4	65	Hand	D			
Encina Fruit Co	19	18	25	1904	Bored, 10 inches	34	4	65	Electric	I	85		
J. Jerrett	30	18	25	1903	Bored, 5 inches	40	5	66	Hand	D			
T. J. Patterson et al	16	18	25	1903	do	42	4	64	do	D			
Ed Bowman	28	18	25		do	42	6	65	do	D			

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T. L. Sharp	21	18	25	1885	....do	40	8?	65	....do	D, S			
S. C. Brown	27	18	25	1875	Bored, 6 inches	38	6	63	....do				
R. E. Hyde	22	18	25		Bored, 7 inches	33	7	64	....do	D			
J. W. Clark	23	18	25		Bored, 5 inches	30	6	64	....do	S			
T. H. Frans	26	18	25	1895	....do	60	6	61	....do	D		30	
A. R. Cutter	23	18	25		....do	40	7	64	....do	D		20	
E. S. Beardsley	13	18	25	1895	Bored, 6 inches	48	9	62	....do	D		25	
M. B. Harris	3	19	23	1904	Bored, 10 inches	42	14		Gas	I		65	937.00
James Brady	2	19	23	1902	Dug, 4 by 8 feet	13	12	69	Hand	D, S		10	4.00
W. L. and F. H. Coughran	1	19	23	1904	Bored, 13 inches	42	14		Gas	I		70	1,480.00
Joe Garcia	36	18	23	1895	Bored, 5 inches	45	8.5	70	Hand	D, S		25	4.00
J. W. Badders	31	18	24		Bored, 6 inches	60	12?	68	....do	D, S		30	4.00
Sam Henderson	6	19	24	1875?	Bored, 5 inches	50	19?	67	Wind	D, S		25	50.00
Packwood school district	6	19	24		Bored, 4 inches	40	12		Hand	D		20	3.50
E. O. Miller	6	19	24	1903	Bored, 7 inches	45	11		Wind	S		35	50.00
C. Hausch	7	19	24	1899	Bored, 4 inches	36	15?	69	....do	D, S		20	50.00
E. O. Miller	5	19	24	1901	Bored, 7 inches	48	11	67	....do	S		35	50.00
Do	5	19	24	1903	....do	40	11?		....do	S		30	50.00
Alta Comstock	4	19	24		Bored, 5 inches	45	7	69	Hand	D, S		25	4.00
Geo. Peterson	28	18	24	1879?	....do	48	4	67	....do	D		25	4.00
Isaac Shirk	28	18	24	1890	....do	60	10?	66	Gas	D, S, I		30	200.00
D. W. Demasters	34	18	24	1890?	Bored, 4 inches	55	2?	67	Hand	D, S		30	4.00
Wiley Coughlan	34	18	24	1900	Bored, 6 inches	40	8		Wind	S		20	50.00
T. A. Elliot	33	18	24	1857	Bored, 5 inches	40	11	67	Hand	D		120	4.00
W. H. & J. F. Putnam	4	19	24		....do	49	7	68	....do	D		25	4.00
A. B. Reese	4	19	24	1890	....do	60	8		Wind	I		30	40.00
Oscar Evans	26	18	24	1903	....do	40	6	66	Hand	D		25	3.50
J. J. & W. J. Fulgham	35	18	24	1905	Bored, 6 inches	48	8?		Gas	D, I, S		25	250.00
R. E. Hyde	25	18	24		Bored, 7 inches	45	4	66	Hand	D		30	4.00
Geo. Pechter	2	19	24	1888?	Bored, 5 inches	68	4	64	....do	D, S		35	4.00
W. H. Roeben	2	19	24		....do	28	8		Wind	S		25	35.00
Philip Aulman	2	19	24		Bored, 8 inches	40	6		....do	S		20	60.00
Do	2	19	24	1896	Bored, 5 inches	58	5.5		....do	D, S		30	75.00
G. Schmidt	1	19	24		....do	40	6	63	Hand	D, S		20	4.00
E. H. & Alfred Daggett	1	19	24	1899	Bored, 10 inches	40	7		Steam	I	44	40	1,500.00
A. Koch	1	19	24	1904	Bored, 5 inches	34	5.5	63	Hand	D, S		20	4.00
Earnest Volguards	1	19	24	1902	Bored, 10 inches	50	7		Gas	I	10	54	300.00
A. T. Griffin	1	19	24	1895	Bored, 5 inches	60	8	62	Hand	D, S		30	4.00
R. Miller	6	19	25	1904	Bored, 6 inches	42	15		....do	S		20	4.00
J. J. Schueller	6	19	25		Bored, 5 inches	54	4	61	....do	S		30	4.00
M. L. Caldwell	6	19	25	1900	....do	65	5	64	....do	D		35	4.00
Clem Caldwell	1	19	24	1902	....do	80	7.5	64	....do	D		40	3.00
S. B. Irwin	12	19	24	1904	Bored, 4 inches	40	8	62	....do	S		20	4.00
P. K. Reese	6	19	25	1903	Bored, 5 inches	50	8	62	....do	D, S		25	3.50
R. Miller	6	19	25	1890	Bored, 6 inches	52	8		Wind	D, S		25	200.00
Mr. Shella	6	19	25	1895	....do	40	6		Hand	D		20	4.00
Mrs. E. Foran	30	18	24		Bored, 5 inches	48	3	68	....do			25	4.00
Mrs. M. Smith	30	18	25		....do	60	4		....do	D			
Visalia City Water Co	30	18	25	1902	Bored, 10 inches	[b] 75	8		Electric	D	44		
Do	29	18	25	1891	Bored, 12 inches	[c] 110	8		....do	D	[a] 90		
Morgan & Alge	28	18	25	1898	Bored, 5 inches	65	4	65	Hand	D, S			

[a] Yield estimated or statement of owner taken. [b] Two wells. [c] Four wells.

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TABLE 55.—*Records of wells in Tulare County*—Continued.

Owner.	Location. Section.	Township south.	Range east.	Year completed.	Type and diameter of well.	Depth of well.	Depth to water level.	Temperature of water.	Method of lift.	Use of water.	Yield.	Cost of well.	Cost of machinery.
						Feet.	*Feet.*	°*F.*			*Miner's inches.*		
E. O. Miller	28	18	25	.....	Bored, 5 inches	35	3.5	65	Hand	S, D	.....	.....	.....
G. F. Beales	32	18	25	1894	....do	45	4.5	.....	Gas	D	.....	.....	.....
B. R. Dennig	28	18	25	1894	....do	42	5	65	Hand	D	.....	.....	.....
Albert Welsh	32	18	25	.....	Bored, 7 inches	66	9	61	....do	D	.....	$50	.....
J. K. Yocum	5	19	25	1902	Bored, 5 inches	34	5	62	....do	D, S	.....	17	$3.00
B. A. Graves	5	19	25	.....	Bored, 6 inches	.....	5	.....	Horse	D, S	.....	.....	100.00
G. W. Bence	5	19	25	.....	Bored, 5 inches	24	6	61	Hand	D, S	.....	16	5.00
S. C. Brown	4	19	25	.....	....do	24	4	62	....do	D	.....	15	3.50
Herbert Luewe	4	19	25	.....	....do	.....	5	62	....do	D, S	.....	.....	3.50
F. Duran	27	18	25	1880	....do	60	5	65	....do	D, S	.....	.....	.....
Fred Uhl	34	18	25	.....	....do	45	5	65	....do	D	.....	.....	.....
J. W. Nelson	3	19	25	1904	....do	64	3	63	Wind	D, S	.....	31	35.00
J. F. Ames	3	19	25	1905	Bored, 12 inches	26	7	.....	....do	D, S	.....	37	40.00
W. H. Blane	3	19	25	.....	Bored, 5 inches	37	4	60	Hand	S	.....	20	3.00
Do	3	19	25	1904	....do	22	5	62	....do	D	.....	15	4.50
Lewis Whittendale	35	18	25	1884	....do	52	6	65	....do	D	.....	.....	.....
L. Mathewson	2	19	25	.....	Bored, 6 inches	65	8	62	....do	D	.....	.....	.....
R. K. Ogden	3	19	25	.....	Bored, 5 inches	50	10	62	....do	D, S	.....	35	3.50
L. J. Mills	11	19	25	1881	....do	60	15?	62	....do	D	.....	40	3.50
L. Mathewson	2	19	25	.....	Bored, 10 inches	65	8	.....	Gas	I	66	70	400.00
Wong Sung	2	19	25	.....	Bored, 6 inches	31	5	62	Hand	D, S	.....	25	4.00
J. P. Dillon	2	19	25	1903	....do	74	7	63	....do	D, S	.....	50	4.00
Geo. Morrell	1	19	25	1901	....do	60	7?	62	....do	D, S	.....	40	3.50
Nellie Lawlers	1	19	25	.....	....do	30	6	66	....do	D	.....	20	4.00
A. M. Thompson	1	19	25	.....	....do	60	8	70	....do	D	.....	45	.....
F. Van Lome	6	19	26	1903	....do	40	8	68	Wind	D, S	.....	20	35.00
Farmersville village	6	19	26	.....	Bored, 4 inches	38	6	67	....do	D, S	.....	.....	.....
C. K. Avery	6	19	26	1903	Bored, 6 inches	34	12	66	Hand	S	.....	17	3.00
L. A. Martin	6	19	26	.....	Bored, 4 inches	43	10	77	....do	D	.....	20	.....
W. Polly	6	19	26	1890	....do	60	4	67	....do	D, S	.....	30	.....
Grant Oak Fruit Co	7	19	26	.....	Bored, 5 inches	30	4	65	....do	S	.....	.....	.....
H. A. Scott	25	18	25	1880?	Bored, 7 inches	103	7	65	....do	D, S	.....	.....	.....
Deep Creek school district	31	18	26	.....	Bored, 5 inches	.....	7.5	64	....do	D	.....	.....	.....
George Neilson	32	18	26	1893	Bored, 4½ inches	56	4	.....	Wind	D, S	.....	.....	.....
Mrs. E. A. Buckman	33	18	26	1889	Bored 5 inches	40	9?	.....	Wind, hand	D, S	.....	.....	.....
B. Schweitzer	27	18	26	.....	Dug, 3 feet	18	13	68	Hand	D	.....	.....	.....
O. H. Fanls	34	18	26	1905	Bored, 7 inches	78	19	.....	Gas	I	a 60	.....	b1,000.00
Mrs. A. M. Catron	4	19	26	1890	Bored, 5 inches	38	15	67	Hand	D	.....	.....	.....

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C. M. Noell	3	19	26		Bored, 4 inches	35	14	67	do	D			
D. V. Robinson	26	17	25	1895	Bored, 7 inches	40	12	70	Wind	S			
H. H. Newman	25	17	25	1892	Bored, 5 inches	50	7	69	Hand	S		25	
J. W. Bacon	24	17	25		do	41	8	68	do	D		20	
M. V. Arnold	30	17	26		Bored, 6 inches	33	13	70	Wind	S			
Mrs. M. F. Swank	30	17	26	1887	Bored, 5 inches	38	12	72	Hand	D			
H. T. Anderson	4	19	26	1890	Bored, 6 inches	35	12	70	Wind	D			
Dillon estate	8	19	26		Bored	40	16	67	do	S			
V. B. Humphrey	4	19	26	1890	Bored, 5 inches	44	15	67	do	S		33	
A. Johnson	9	19	26	1891	do	30	14	65	Hand	D		25	
Frank Emery	3	19	26	1903	Bored, 10 inches	90	26	72	Gas	I	18		[b] 750.00
J. F. Firebaugh	3	19	26	1904	do	113	31		Electric	I	[a] 48	500	1,000.00
C. N. Jordan	3	19	26	1904	do	84	32	72	do	I	15		
B. F. Teague	10	19	26	1903	do	60	26		Gas	D	8		
Ostrander & Son	11	19	26	1901	do	99	30		Electric	I	28		
Horace Davis	10	19	26	1905	do	76	30		Gas	I	2		
Norcross & Crane	11	19	26	1904	Bored, 8 inches	85	31	72	Electric	I	26		
B. F. Teague	11	19	26	1904	Bored, 10 inches	85	30	72	do	I	16	160	
Pozo Grande Vineyard	2	19	26	1904	do	128	42	72	do	I	48		
F. Moxon	3	19	26	1902	do	95	32	70	do	I	[a] 3	200	850.00
H. Lacesse	2	19	26	1903	Bored, 6 inches	62	42	66	Wind	D		30	125.00
A. R. Carney	2	19	26	1890	Bored, 10 inches	65	40	67	Electric	I		45	650.00
E. Patten	1	19	26	1903	do	100	40		do	I	40	125	950.00
Do	11	19	26		Bored, 5 inches	56	38	68	Hand	D			
C. E. Joyner	12	19	26	1885	Bored, 6 inches	62	40	68	Wind	D		62	
T. W. Potter	35	18	26	1905	Dug, 2 feet	90	42	72	Electric	I	31		
J. P. Daly	35	18	26	1888	Bored, 5 inches	62	30		Wind, hand	D, S			
A. R. Carney	36	18	26		Bored, 10 inches	+90	42		Electric	I	18		
Do	36	18	26		do	65	41	72	do	I	22		
Do	25	18	26		do	65	40	72	do	I	22		
Merriman Fruit, Land & Lumber Co	36	18	26	1903	do	250	43	71	do	I	[b] 9	250	
Do	36	18	26	1903	do	80	38		do	I	18		
Badger Irrigation Co	30	18	27		do	85	40		do	I	[a] 19		
Do	30	18	27	1898	do	85	31		do	I	[a] 25		
Do	31	18	27	1902	do	85	44	70	do	I	[a] 40		
Roeding & Wood	12	19	26	1904	do	110	32	70	Gas	I	12	220	1,000.00
A. Ahlm	24	19	26	1897	Bored, 4 inches	46	30	72	do	I			
M. E. Newhall	18	19	27		Bored, 10 inches	90	33		Electric	I	31		
Wm. Mitchel estate	19	19	27	1904	do	75	32		do	I	40	200	800.00
J. F. Dungan	19	19	27	1903	do	65	26	72	do	I	16		
A. N. Dreisbach	19	19	27	1903	Bored, 4 inches	50	20	74	do	I	15	75	500.00
Burr Bros	19	19	27	1898	Bored, 8 inches	65	20	71	Wind	D, S			
Lindsay Heights Water Co	30	19	27		Bored, 11 inches	107	28	69	Electric	I	38		
Do	30	19	27		do	75	28	69	do	I			
Do	30	19	27		do	110	28	70	do	I	32		
W. E. Carder	10	19	26	1902	Bored, 5 inches	43	20	73	Wind	D, S		30	
Mr. Bowman	14	19	26		Dug	30	24	69	Hand	S			
S. H. West	15	19	26	1890	Bored, 6 inches	40	20	73	Wind	D, S			
J. Tuthy	16	19	26		do	60	13	68	do	D, S			
J. H. Hart	22	19	26	1885	do	20	14	72	Hand	D			
H. T. Anderson	21	19	26		Bored, 5 inches	30	16	72	do	D			

[a] Yield estimated or statement of owner taken.

[b] Cost of well and equipment combined.

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TABLE 55.—*Records of wells in Tulare County*—Continued.

Owner.	Location. Section.	Township south.	Range east.	Year completed.	Type and diameter of well.	Depth of well.	Depth to water level.	Temperature of water.	Method of lift.	Use of water.	Yield.	Cost of well.	Cost of machinery.
						Feet.	*Feet.*	°*F.*			*Miner's inches.*		
B. F. Dailey	22	19	26	1904	Bored, 10 inches	60	14	72	Gas	I	18		$350.00
Kibler estate	23	19	26	.....	Dug, 2 feet	24	20	72	Wind	S	.....	.....	.....
C. W. Hart	21	19	26	.....	Bored, 5 inches	26	9	70	....do	S	.....	.....	.....
R. S. Vanderburg	28	19	26	.....	Bored, 6 inches	20	9	72	....do	S	.....	$10	.....
Do	28	19	26	1903	Bored, 10 inches	70	9	73	Horse	I	.....	70	50.00
A. C. Kuhn	18	19	26	1904	....do	50	15	.....	.....	.....	.....	.....	.....
C. W. Hart	20	19	26	1905	Bored, 5 inches	50	10	68	Hand	D	.....	25	.....
School district	18	19	26	.....	....do	50	11	69	....do	D	.....	.....	.....
B. F. Bequette	19	19	26	1890	....do	34	11	69	....do	D	.....	17	.....
Mrs. F. D. Rice	30	19	26	1885	....do	50	8	69	....do	D	.....	25	.....
J. Rice	19	19	26	1897	Bored, 4 inches	62	8	71	....do	D, S	.....	30	.....
L. N. Wood	25	19	25	.....	Bored, 5 inches	46	8	70	Wind	D, S	.....	.....	.....
E. F. Hart	12	19	25	.....	....do	70	6	63	Hand	D	.....	45	10.00
Pasco Bequette	11	19	25	.....	....do	39	4	62	....do	D, S	.....	25	3.00
J. W. Hart	13	19	25	1880	....do	42	14?	62	....do	D, S	.....	40	4.50
John Markes	14	19	25	1890	Bored, 6 inches	60	10	62	....do	D, S	.....	30	3.00
J. C. Campbell	24	19	25	1892?	Bored, 8 inches	47	8	.....	Wind	D, S	.....	35	.....
J. W. Griffin	24	19	25	1890	....do	72	10?	65	Hand, wind	D	.....	50	30.00
W. A. Mills	11	19	25	1891	Bored, 5 inches	33	6	64	Hand	D, S	.....	20	3.50
J. M. Dye	11	19	25	.....	....do	32	7	63	....do	D	.....	20	3.50
Sam Huth	15	19	25	.....	....do	33	6	64	....do	D	.....	20	3.50
Joe Summers	10	19	25	1905	....do	46	7	65	....do	D	.....	35	3.50
London, Paris & American Bank	15	19	25	1899	Bored, 10 inches	110	10	.....	Gas	I	[a] 300	110	1,400.00
W. S. Winans	34	19	25	.....	Bored, 5 inches	41	4	64	Hand	D, S	.....	25	4.50
Mr. Doherty	26	19	25	.....	....do	23	5	.....	Wind	D, I, S	.....	15	65.00
Wm. Swall	35	19	25	.....	....do	38	4.5	64	Hand	S	.....	24	5.00
Jas. H. Morton	28	19	25	1897	Bored, 10 inches	85	10	.....	Electric	I	144	300	1,300.00
Do	28	19	25	1897	....do	65	10	.....	....do	I			
Wm. Swall	29	19	25	1902	Bored, 7 inches	65	10	62	Steam	I	.....	65	260.00
J. C. Mosier	20	19	25	1888	Bored, 10 inches	34	8	64	Hand	D, S	.....	30	5.00
London, Paris & American Bank	16	19	25	.....	Bored, 5 inches	41	10	.....	Wind	D, S	.....	21	75.00
H. C. Higby	8	19	25	1870	....do	40	8	61	Hand	D	.....	30	5.00
F. J. Tucker	12	19	26	1905	Bored, 6 inches	42	6	65	....do	S	.....	25	4.50
G. H. Hubbell	18	19	25	1874	Bored, 5 inches	60	8	63	....do	D	.....	30	3.50
John C. Hawkins	19	19	25	1887	....do	30	10	63	....do	D, S	.....	15	4.50
Geo. Swall	20	19	25	.....	Bored, 8 inches	49	9	64	....do	D, S	.....	35	9.00
Mr. Reeves	29	19	25	.....	Bored, 5 inches	34	11	64	....do	D, S	.....	15	4.00
William Swall	29	19	25	1904	Bored, 8 inches	50	10	64	....do	D, S	.....	35	10.00

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Mrs. M. A. Edgar	32	19	25	1904	Bored, 5 inches	105	12	62	do	D, S		50	4.00
J. P. Brown	30	29	25		Bored, 5 inches	62	10	63	do	D		30	4.00
A. W. Smith	31	19	25	1901	Bored, 2 inches	60	10	65	Wind	D, S			60.00
John Mants	30	19	25		Bored, 7 inches	24	10	65	do	S		20	65.00
A. H. Collins	2?	19	24	1903	Bored, 5 inches	44	14	64	Hand	D		25	4.00
G. W. Filmore	4	19	24		do	65	10	64	Wind	S		30	75.00
E. H. Fisher	19	19	25	1903	do	78	10	65	Hand	S		45	22.00
C. R. Scott	19	19	25	1901	Bored, 6 inches	47	10	62	do	D, S		25	4.00
A. O. Carmichael	13	19	24		Bored, 8 inches	32	7		Horse	D, S		25	60.00
E. O. Larkin	12	19	24		do		7		do	D, S			100.00
Do	12	19	24	1899?	Bored, 5 inches	70	5	64	Hand	D		35	4.00
J. H. Kinkaid	12	19	24	1886	do	38	8		do	D		20	4.00
John Findley	14	19	24	1891	do	50	7	64	do	D, S		25	15.00
A. E. Glare	13	19	24		Bored, 6 inches		8	64	do	D, S			4.00
Mrs. D. K. Zumalt	13	19	24		do	40	12?	64	do	D, S		20	4.00
Mrs. Emma Zumalt	23	19	24		Bored, 10 inches	70	8		Steam	S		70	150.00
I. L. Jimmerson	24	19	24		Bored, 8 inches	50		66	Wind	D, S		35	60.00
D. L. Bickley	25	19	24	1904	Bored, 5 inches	46	10		do	S		25	40.00
J. M. Segress	25	19	24		do	60	8	65	Hand	D		30	4.00
Mrs. M. McKamish	25	19	24		Bored, 8 inches	48	9		Horse	S		35	75.00
Wm. Bruce	26	29	24	1881	do	51	11	66	Hand	D		40	4.00
J. R. Williams	35	19	24		Bored, 5 inches	50	10	68	do	D, S		25	4.00
Mrs. Emma Zumalt	23	19	24	1902	Bored, 6 inches	30	8		do	S		15	4.00
Wm. Robertson	16	19	24		Bored, 5 inches		11	60	Wind	D, S			50.00
Albert Nelson	15	19	24	1887	Bored, 6 inches	34	11	69	do	D, S		20	65.00
Goldman & Bachman	21	19	24	1903	Bored, 11 inches	65	10		Gas	I		65	
Do	21	19	24	1903	do	85	10		do	I		85	
E. Renaud	22	19	24	1880	Bored, 5 inches	60	11		Wind	S		30	45.00
F. J. Gist	28	19	24	1887	do	60	11	66	Horse	D, S			
H. P. Anderson	27	19	24	1903	do	65	8		Wind	D, S		33	45.00
Mr. Barber	27	19	24	1905	do	75	10		Hand	D		40	4.00
F. J. Gist	28	19	24		do	45	9	65	Horse	D, S		25	60.00
E. Lathrop	28	19	24		Bored, 8 inches	32	9	68	Wind	D, S		25	75.00
F. P. Robertson	33	19	24	1884	do		10		do	D, S			65.00
T. T. Sullivan	33	19	24		Bored, 5 inches		9	67	Hand, horse	D, S			25.00
Alzina Benc	29	19	24	1884?	Bored, 6 inches	38	8	68	Hand	D, S		20	4.00
W. G. Parsons	32	19	24		Bored, 7 inches	60	13	70	Wind	D, S		35	50.00
Thomas J. Barringer	29	19	24		Bored, 5 inches	72	15	68	Hand	D		35	4.00
John Moller	20	19	24	1893	Bored, 4 inches	30	15	68	Wind	D, S		15	45.00
I. D. Reinhart	20	19	24		Bored, 5 inches	24	8	69	Hand	D		15	4.00
P. E. Reinhart	21	19	24	1901	Bored, 6 inches	43	6		Wind	D, S		20	65.00
A. Mitchell	8	19	24	1888	Bored, 5 inches	70	12?	68		D		35	4.00
C. Hausch	7	19	24	1874	Bored, 4 inches	36	15		Wind	S		20	50.00
Do	7	19	24	1897	do	36	15		do	S		20	50.00
Wm. March	12	19	23	1902	Bored, 5 inches	44	7	69	do	S		20	50.00
Chas. Hausch	13	19	23	1899	Bored, 6 inches	60	12?	68	Hand	D		30	50.00
B. Noussiton	24	19	23	1888	Bored, 10 inches	53	11		Wind, horse	D, S		40	
Geo. Heidt	19	19	24	1881	Bored, 5 inches	50	9?	69	Wind	D, I		25	50.00
Henry Colpien	29	19	24	1900	Bored, 4 inches	50	15		do	D, S		25	55.00
E. M. Pugh	29	19	24		Bored, 5 inches	60	14		Not raised	N		30	
S. S. Inge	31	19	24	1875	Bored, 4 inches	64	11		Wind	D, S		30	45.00

[a] Yield estimated or statement of owner taken.

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TABLE 55.—*Records of wells in Tulare County*—Continued.

Owner.	Location.			Year completed.	Type and diameter of well.	Depth of well.	Depth to water level.	Temperature of water.	Method of lift.	Use of water.	Yield.	Cost of well.	Cost of machinery.
	Section.	Township south.	Range east.										
						Feet.	*Feet.*	°*F.*			*Miner's inches.*		
M. A. Moorehead	30	19	24	1890	Bored, 7 inches	32	8	66	Wind, hand	D, S		$16	$5.00
Oakland Savings Bank	36	19	23	1903	Bored, 10 inches	465	1.5	76	Electric	I	a 110	1,800	100.00
Do	36	19	23		do	580	4		Not raised	N			
Frank Mattos	26	19	23	1895	Bored, 6 inches	62	12		Wind	S		30	50.00
W. J. Brown	24	19	23	1903	Bored, 8 inches	35	12		Hand	D		20	4.00
Do	24	19	23	1905	Bored, 6 inches	21	12		do	S		10	4.00
Henry Banker	12	19	23	1902	Bored, 5 inches	24	8		Wind	S		12	50.00
R. Chatten	11	19	23	1862	Bored, 6 inches	40	9	69	Horse	D, S			50.00
Linder school district	27	19	23		Bored, 5 inches	102	13	69	Hand	D		50	4.00
John Fleming	34	19	23	1885	do	48	16	69	do	D. S			18.00
Do	28	19	23	1903	do	68	16		Wind	S			50.00
M. & J. Fleming	34	19	23	1898	do	78	16		Not raised	N		40	
B. T. Watson	28	19	23	1904	Bored, 12 inches	61	12		Gas	I		60	600.00
Wm. Hoffsneider	19	19	23	1903	do	171	14		do	I		170	1,000.00
A. Baird	29	19	23	1884	Bored, 8 inches	420	0	75	Artesian	I	8	1,000	
R. E. Keeler	31	19	23	1884	do	430	0	76	do	I	5	1,000	
Louis Bertch	4	20	23		Bored, 7 inches	80	10	71	Hand	D		50	4.00
Mrs. Geo. Bertch	7	20	23	1882	do	470	0	74	Artesian	I, S		1,200	
Do	7	20	23	1895	Bored, 9 inches	60	8		Steam	I		60	6.00
San Francisco Savings Union	18	20	23	1882	Bored, 7 inches	462	0	74	Artesian	S, I	2		
Manuel Machado	17	20	23		Bored, 5 inches	58	11	72	Hand	D		30	4.00
Jacob Bertch	16	20	23	1885	Bored, 7 inches	480	0	74	Artesian	I	14	1,000	
E. H. Kemble	9	20	23	1892	Bored, 8 inches	36	16?	68	Hand	D, S		25	4.00
S. F. Hoover	10	20	23	1888	Bored, 9 inches	505	0	74	Artesian 5	I, D	6		
Page & Monteagle	3	20	23		Bored, 5 inches	68	7	66	Wind	S		35	50.00
Do	3	20	23		Bored, 8 inches	60	7		Horse	S		35	50.00
Albert Knapp	11	20	23	1891?	Bored, 9 inches	1,150	0	75	Artesian	I	21	2,000	
C. M. Hatch	11	20	23	1887	Bored, 7 inches	441	0		do	I	17		
Do	11	20	23	1899	Bored, 12 inches	87	11.5		Steam	I		200	1,000.00
I. P. Beal	14	20	23		Bored, 8 inches	80	8		Horse	D, S		60	50.00
J. Goldman & Co	12	20	23	1899	Bored, 5 inches	40	10	69	Hand	D, S		20	4.00
John Hanesy	1	20	23	1905	Bored, 12 inches	600	0		Electric	I	a 83	1,500	600.00
Samuel Handy	7	20	24		do	b 147	8		do	N		200	
Do	7	20	24		do	90	8?		do	N			
Laural school district	6	20	24		Bored, 5 inches	46	13		Hand	D		20	4.00
W. C. Carpenter	5	20	24		do	34	13	68	do	D, S		20	4.00
J. R. Clemens	32	19	24		Bored, 7 inches	700?	12		Wind	D, S			65.00
D. J. Knapp	5	20	24		Bored, 6 inches	65			Hand	S		40	4.00

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C. H. Slaughter	4	20	24	1893	....do	60	8	66	....do	D		35	4.00	
T. J. Mull	5	20	24	1901	Bored, 11 inches	430	7.5	73	Electric	I	24	700	1,000.00	
Page & Monteagle	8	20	24	1900	....do	170	15	70	....do	I	110		[c]4,000.00	
Do	8	20	24	1900	....do	170	15	70	....do	I	76			
Mrs. Geo. Bertch	4	20	24	1903	Bored, 5 inches	116	13	68	Hand	D, S		76	4.00	
G. W. Frees	9	20	24	1903	Bored, 6 inches	56	13	65	....do	D, S		35	4.00	
R. B. Holcomb	4	20	24	1896	Bored, 8 inches	58	10	67	....do	D, S		50	4.00	
J. H. Morton	8	20	24		Bored, 10 inches	80	12		Horse	D, S		80	75.00	
Tulare City Water Co	10	20	24	1887	....do	525	12		Electric	D		1,348		
Do	10	20	24	1887	....do	490	12		....do	D	166			
Do.[b]	10	20	24	1887	Bored, 8 inches	350	12		....do	D				
C. Ellison	34	19	24	1904	Bored, 5 inches	40	8?	70	Hand	D, S		20	4.00	
G. Linegrover	34	19	24		....do	34	5	66	Wind and hand	S		20	60.00	
F. H. Butler	35	19	24	1903	....do	35	10	66	Wind	D, S		50	45.00	
U. S. G. Mills	35	19	24	1903	....do	45	12	68	Hand	D, S		35	4.00	
A. G. Woodward	11	20	24	1897	....do	34	9	70	....do	D		20	4.00	
S. Gavatte	12	20	24		....do	23?	11		Horse	D, S			50.00	
O. F. Manock	13	20	24	1903	Bored, 6 inches	68	15	66	Hand	D, S		30	4.00	
D. Kazaian	1	20	24		Bored, 5 inches	62	9	68	....do	D, S		30	4.00	
J. M. Smith	6	20	25		....do	40		68	Wind	D, S		20	30.00	
A. M. Wells	6	20	25		....do	61	9	67	Hand	D, S		30	4.00	
D. J. F. Reed	7	20	25		....do	60	9	66	....do	D, S		30	4.00	
T. N. Johnson	7	20	25	1893	Bored, 8 inches	700	8.5		Wind	D, S		1,600	50.00	
Tulare Colony	5	20	25		Bored, 5 inches	60	9.5		....do	D, S		30	50.00	
M. Brown	32	19	25	1901	....do	60	4?	67	Hand	D, S		30	4.00	
W. Isley	32	19	25	1893	....do	44	9	67	....do	D		45	4.00	
A. N. Budd	5	20	25	1902	....do	60	12?	67	....do	D, S		40	4.00	
W. H. Kelley	32	19	25	1900	....do	65	8	67	....do	D, S		35	4.00	
J. T. Lawson	32	19	25		....do		7	66	Wind	D, S			50.00	
A. Peterson	5	20	25	1903	Bored, 7 inches	34	5		....do	S		25	40.00	
W. T. Caldwell	5	20	25		Bored, 5 inches	36	4	67	....do	D, S		20	50.00	
C. M. Medder	4	20	25	1904	....do	52	4	69	Hand	D, S		25	4.00	
C. J. Shannon	33	19	25		Bored, 7 inches	49	5	64	....do	D		40	4.00	
G. W. Gluyas	33	19	25	1901	Bored, 5 inches	+100	8	67	....do	D, S			4.00	
F. C. Wagner	4	20	25		Bored, 7 inches	36	3.5		Horse	S		25	50.00	
F. Gianini	8	20	25		Bored, 5 inches	37	5.5		Wind	S		20	50.00	
Albert Henry	34	19	25		....do	46	7	68	Hand	D, S		25	4.00	
F. Pospishek	11	20	25	1905	....do	49	3.5	67	....do	D		24	4.00	
J. M. Birkhead	12	20	25	1902	Bored, 7 inches	21	3.5		Not raised	N		15		
H. Mohr	1	20	25		Bored, 5 inches	60	4		Hand	S		30	4.00	
Judge Gray	36	19	25	1893	....do	56	8	70	....do	D		30		
J. F. Sullinger	6	20	26	1902	Bored, 6 inches	48	12	72	Gas	D, S	7	35	200.00	
H. Mohr	6	20	26		Bored, 5 inches	33	8	71	Hand	D, S				
R. E. Hyde	12	20	25		....do	24	3.5	68	....do	S		10	4.00	
P. Burkhead	12	20	25		Bored, 6 inches	31	9	69	Wind	D, S				
G. W. Wray	7	20	26		Bored, 5 inches	28	9	72	....do	S				
G. Baumann	4	20	26	1893	....do	40	12	70	....do	D, S		20	50.00	
T. Stillwell	33	19	26	1901	Bored, 6 inches	30	9	70	....do	D, S		20	40.00	
J. W. Archer	34	19	26		Bored, 5 inches	26	9		....do	S				
T. Stillwell	34	19	26	1901	Bored, 6 inches	30	8	71	....do	S		20	35.00	
Do	26	19	26	1901	....do			69	....do	D, S		20	40.00	

[a] Yield estimated or statement of owner taken.

[b] Two wells.

[c] Cost of well and equipment combined.

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TABLE 55.—*Records of wells in Tulare County*—Continued.

Owner.	Location.			Year completed.	Type and diameter of well.	Depth of well.	Depth to water level.	Temperature of water.	Method of lift.	Use of water.	Yield.	Cost of well.	Cost of machinery.
	Section.	Township south.	Range east.										
						Feet.	*Feet.*	°*F.*			*Miner's inches.*		
C. P. Mayberry	34	19	26	1905	Bored, 10 inches	58	14	.....	Gas	I	15	$75	$165.00
J. W. Sturgeon	4	20	26	.....	Bored, 5 inches	39	11	68	Wind	S	.....	.....	.....
A. Swanson	3	20	26	.....	do	40	12	72	do	D, S	.....	.....	.....
Mrs. S. Navarre	2	20	26	.....	do	60	18	70	Hand	D	.....	.....	.....
J. Huskins	2	20	26	1895	Bored, 7 inches	45	22	72	do	D	.....	25	.....
Mrs. W. R. Ray	2	20	26	1883	Bored, 5 inches	40	14	73	Wind	D, S	.....	.....	.....
J. C. Green	6	20	27	1905	Bored, 8 inches	65	28	75	Electric	I	.....	.....	.....
J. Taylor	6	20	27	1902	Bored, 9 inches	85	43	75	do	I	18	85	750.00
Do	6	20	27	1902	do	150	43	73	do	I		150	
J. McKeller	6	20	27	1905	Bored, 10 inches	150	29	72	.....	.....	.....	150	.....
G. K. Hostetter [a]	6	20	27	1905	Bored, 8 inches	250	38	73	Gas	I	22	500	600.00
J. McKeller	6	20	27	1901	Bored, 11 inches	130	46	.....	Electric	I	8	.....	[b] 800.00
Camille Ranch Co	5	20	27	1905	Bored, 12 inches	245	52	73	do	I	42	.....	3,000.00
Do	5	20	27	1898	(c)	70	40	69	do	I	7	.....	.....
H. W. Dunlap	5	20	27	1905	Bored, 10 inches	225	24	.....	do	I	[d] 9	.....	[b] 1,000.00
Fuller & Graybill	32	19	27	1905	Bored	220	70	75	Gas	I	10	.....	[b] 2,600.00
W. S. Galyan	32	19	27	1905	Bored, 10 inches	187	100	74	Electric	I	8	.....	.....
John Hedberg	4	20	27	1905	do	153	82	.....	do	I	[d] 12	.....	[b] 762.00
E. L. Daniels	4	20	27	1903	do	185	60	.....	.....	I	[d] 15	.....	.....
D. O. Bishop	4	20	27	1904	do	200	60	75	Electric	I	6	.....	1,500.00
F. J. Fountain	5	20	27	1902	Bored, 8 inches	190	60	73	do	I	6	.....	.....
A. Godding	5	20	27	.....	Bored, 10 inches	175	62	71	do	I	4	.....	.....
A. E. Berry	5	20	27	1900	do	200	45	.....	do	I	.....	.....	.....
W. B. Buxton	4	20	27	1904	Bored, 8 inches	176	78	74	do	I	[d] 5	.....	.....
Whitmore Bros	4	20	27	1904	Bored, 10 inches	250	84	.....	do	I	12	700	2,000.00
Do	4	20	27	1900	(e)	157	87	.....	do	I	[d] 7	350	800.00
John Hedberg	3	20	27	1905	Bored, 10 inches	191	42	.....	do	I	[d] 32	500	2,300.00
J. L. Tuohy	2	20	27	1905	Dug	17	11	.....	do	I	[d] 7	.....	.....
E. A. Batchelder	10	20	27	.....	Bored, 11 inches	170	40	.....	Gas	I	20	.....	[b] 550.00
W. F. Cowan	9	20	27	1905	Bored, 12 inches	153	67	74	Electric	I	4	.....	[b] 725.00
C. R. Rice	9	20	27	1905	do	197	70	.....	do	I	[d] 5	325	800.00
C. H. Boardman	16	20	27	1905	do	165	70	.....	do	I	6	.....	1,150.00
J. N. Bergen	9	20	27	1904	Bored, 8 inches	140	65	.....	Gas	I	4	.....	600.00
Nob Hill Water Co	8	20	27	1900	(f)	190	65	.....	Electric	I	38	.....	[b] 2,000.00
N. S. Marshall	16	20	27	1905	Bored, 10 inches	201	60	.....	do	I	13	.....	1,400.00
C. Hendricks	7	20	27	1905	Bored, 8 inches	130	60	74	Gas	I	2	65	105.00
J. N. Birkhead	7	20	27	1905	Bored, 10 inches	124	47	.....	do	I	11	.....	[b] 1,050.00
A. Z. Roberts	7	20	27	1904	do	148	47	.....	Electric	I	1	.....	.....

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Mrs. A. H. Hersey	18	20	27	1905	....do	210	52	74	....do	I	38			2,000.00
J. de Martini	17	20	27	1903	Bored, 12 inches	225	58?		....do	I	d 30			
Do	17	20	27	1905	....do	215	60	74	....do	I	35			
Ruby Johnson	18	20	27	1900	Bored, 10 inches		47		....do	I	9			
W. C. Stelling	18	20	27	1902	Bored, 8 inches	90	45?		....do	I				b1,000.00
J. O. Culver	17	20	27	1904	Bored, 10 inches	138	51	74	....do	I	7			1,050.00
K. H. Plate	18	20	27	1902	....do	190	50	74	....do	I	17			
Do	18	20	27	1902	....do	130								
Lindsay Irrigation Co. g	18	20	27	1901	....do	80	55		....do	I	22			
C. O. Cowles	18	20	27	1903	Bored, 8 inches	182	42		....do	I	14			b1,000.00
Hugh Latimer	18	20	27	1900	Bored, 10 inches	160	45		....do	I				
Do	18	20	27	1900	....do	90								
J. E. Coombs	18	20	27	1904	Bored, 12 inches	81	56?	74	....do	I	12			
Mrs. E. G. Stelling	7	20	27	1903	Bored, 8 inches	145	45?		....do	I	9			b1,500.00
E. C. Graham	7	20	27	1904	....do	142	47	74	....do	I	1			
C. J. Carle	7	20	27	1899	Bored, 10 inches	148	26		....do	I	14			1,200.00
Mount Whitney Power Co	7	20	27	1904	Bored, 13 inches	208	47	74	....do	D	11			
Camille Ranch Co	12	20	26	1897	Bored, 10 inches	65	40		....do	I	7			
Lindsay Water Development Co	12	20	26	1900	....do	82	42	74	....do	I	75			
Do	12	20	26	1900	....do	500								
L. S. White	12	20	26	1899	....do	135	48	74	....do	I	16			
Do	12	20	26	1899	....do	95								
R. E. Pierce	12	20	26	1895	....do	170	45		....do	I	23			
Do	12	20	26	1895	....do	85								
C. O. Cowles	12	20	26	1902	Bored, 8 inches	142	40	74	....do	I	5			b 500.00
G. W. Fletcher	13	20	26	1905	Bored, 10 inches	93	40	72	....do	I	10	36		500.00
Paradise Water Co	13	20	26	1900	Bored, 12 inches		45?	74	....do	I	27			
Mrs. M. E. Irwin	12	20	26	1903	Bored, 10 inches	70	49	74	....do	I	17			
J. W. Graybill	12	20	26	1900	Bored, 8 inches	70	40	73	....do	I	8	50		
S. Wolf	12	20	26	1905	....do	75	40		....do	I	d 16			
W. E. Porter	12	20	26	1901	....do	75	40	73	....do	I	11	75		400.00
J. B. Eager	12	20	26	1900	....do	80	29?		....do	I	11			350.00
W. McIndoo	12	20	26	1905	....do	70	38		....do	I	20	50		600.00
McIndoo & McLeis Bros	11	20	26	1904	Bored, 10 inches	85	40	73	....do	I	d 28			
J. Goldman	13	20	26	1899	....do	80	40		....do	I	d 37			1,250.00
J. Orton	14	20	26	1885	Bored, 7 inches	50	26	74	Hand	S				
J. T. Orton	13	20	26	1890	....do	40	30	73	Wind	D, S				
Keeley Bros	24	20	26	1890	....do	50	30	70	Hand	D, S				
J. J. Cairns	11	20	26	1900	Bored, 10 inches	70	20	69	Electric	D, S	4	50		
Do	11	20	26	1902	....do	75	20		....do	I	d 60			
Do	11	20	26	1891	Bored, 12 inches	275	20		....do	I	d 135			
M. R. Madary	11	20	26	1903	Bored, 6 inches	200	30	71	....do	I	d 56			
T. N. Jarrard	10	20	26	1885	Bored, 7 inches	40	20	69	Wind	D		25		50.00
R. A. Rodgers	16	20	26	1904	Bored, 6 inches	28	11	69	....do	D, S				
S. Bond	20	20	27	1895	Bored, 5 inches	62	36		....do	D		60		
A. Hunsaker	20	20	27	1885	....do	60	40	74	....do	D, S				
J. Goldman	30	20	27	1882	Bored, 6 inches	50	34		....do	D, S				
J. B. Chinn	21	20	27	1895	Bored, 7 inches	70	40	76	....do	D, S		70		

a Two wells.
b Cost of well and equipment combined.
c Dug 6 by 6 feet 40 feet deep and bored 30 feet by 12 inches diameter.
d Yield estimated or statement of owner taken.
e Dug 82 feet and bored 75 feet by 8 inches diameter.
f Dug 80 feet and bored 110 feet by 12 inches diameter.
g Six wells.

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TABLE 55.—*Records of wells in Tulare County*—Continued.

Owner.	Location.			Year completed.	Type and diameter of well.	Depth of well.	Depth to water level.	Temperature of water.	Method of lift.	Use of water.	Yield.	Cost of machinery.	Cost of well.
	Section.	Township south.	Range east.										
						Feet.	*Feet.*	°*F.*			*Miner's inches.*		
Strathmore ranch	27	20	27	.....	Bored, 10 inches...	203	51	.....	Not raised	N	.....	.....	.....
Do	27	20	27	.....	Bored, 15 inches...	220	60	.....	....do	N	.....	.....	.....
Do	27	20	27	.....	Bored, 12 inches...	227	68	.....	....do	N	.....	.....	.....
El Mirador Land Co	23	20	27	1905	Bored, 10 inches...	283	65	70	....do	I	.....	.....	$2,000.00
P. J. Montgomery	24	20	27	1905	Bored, 12 inches...	301	70?	.....	....do	I	.....	.....	2,000.00
Strathmore ranch	35	20	27	.....	....do	220	44	.....	Not raised	.....	.....	.....	.....
P. Griffin	2	21	27	1880	Bored, 6 inches....	35	18	69	Wind	D, S	.....	.....	.....
J. K. Cramer	2	21	27	1898	Bored, 7 inches....	70	16	.....	Horse	I	.....	$54	125.00
J. Linden	34	20	27	1903	....do	85	16	70	Wind	D	.....	.....	.....
J. M. Van Emon	32	20	27	.....	Bored, 6 inches....	56	20	71	....do	D, S	.....	60	.....
J. Weisenberger	10	21	27	1905	Bored, 12 inches...	175	35	71	....do	.....	.....	480	75.00
C. W. Buswell	10	21	27	1904	Bored, 10 inches...	195	16	74	Electric	I	[a] 13	.....	870.00
Hemphill & Larson	14	21	27	1904	Bored, 12 inches...	64	38	.....	....do	I	[a] 15	63	1,500.00
Sunnyside Water Co.[b]	23	21	27	1902	Bored, 10 inches...	100–150	20	71	....do	I	[a] 40	.....	.....
Hilo Pump	23	21	27	1904	Bored, 12 inches...	165	42	.....	....do	I	[a] 45	600	4,000.00
J. H. Williams & Co	21	21	27	1902	Bored, 8 inches....	30	4	68	Hand	D	.....	.....	.....
F. A. Kelly	21	21	27	1897	Bored, 5 inches....	36	7	70	....do	D	.....	.....	.....
F. E. Henderson	20	21	27	1882	Bored, 7 inches....	44	7	70	Wind	D, S	.....	45	.....
W. H. Castle	17	21	27	1895	Bored, 5 inches....	30	6	69	Hand	D	.....	15	.....
A. Hansaker	13	21	26	.....	Bored, 6 inches....	43	8	67	....do	D	.....	.....	.....
Mrs. R. Kirby	11	21	26	1899	Bored, 4 inches....	30	9	66	....do	D	.....	.....	.....
J. B. Chinn	14	21	26	1890	Bored, 6 inches....	40	10	70	Wind	S	.....	.....	.....
M. Braverman	15	21	26	.....	Bored, 5 inches....	40	9	70	Hand	D, S	.....	40	.....
Kelley Bros	11	21	26	1893	....do	52	9	.....	....do	S	.....	.....	.....
F. Stone	10	21	26	1885	....do	50	10	66	....do	D	.....	50	.....
P. Spuhler	10	21	26	1895	Bored, 8 inches....	46	9	67	Wind	S	.....	.....	.....
O. Miller	34	20	26	1875	Bored, 7 inches....	33	9	69	Horse	S	.....	30	.....
P. Spuhler	9	21	26	1887	....do	64	8	66	Wind	D, S	.....	.....	.....
A. T. McGee	4	21	26	1872?	Bored, 6 inches....	60	10	70	Hand	D	.....	.....	.....
W. H. Vaughan	32	20	26	1905	Bored, 7 inches....	63	18	.....	Gas	I	50	.....	.....
C. J. Martin	6	21	26	.....	Bored, 3 inches....	30	15	69	Hand	D	.....	.....	.....
H. Hunsaker	25	20	25	.....	Dug	.....	13	.....	Horse, wind	S	.....	.....	85.00
Stadmiller & Rising	2	21	25	.....	Bored, 5 inches....	41	12	69	Hand	D, S	.....	20	4.50
Mr. Morris	34	20	25	.....	....do	30	12	69	....do	D	.....	15	4.50
Mr. Crabtree	20	20	25	.....	....do	.....	10	71	Wind	D, S	.....	.....	50.00
J. M. Estes	20	20	25	1902	....do	85	12?	70	Hand	D, S	.....	47	4.50
J. T. Turner	19	20	25	1897	Bored, 7 inches....	90	8	.....	Wind, horse	D, S	.....	60	195.00
J. H. Abaher	19	20	25	.....	Bored, 4 inches....	30	7	.....	Wind	D, S	.....	15	50.00

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Wm. Carpenter	18	20	25	1905	Bored, 5 inches	35	7.5		Hand	D, S		17	5.00
J. B. Walker	13	20	24		do	30	6	69	do	D, S		15	4.00
U. S. Experiment Station	14	20	24	1901	Bored, 10 inches	76	11		Gas	I	17	76	300.00
				1888	do	56	10		Horse	I	8	56	175.00
James Turner	4	20	24		Bored, 7 inches	60	11		Gas	S		35	240.00
James Hinton	10	20	24		Bored, 8 inches	60	12		do	I		45	250.00
J. H. McDonald	15	20	24	1889?	Bored, 5 inches	40	15?	70	Hand	D, S		20	4.00
P. Williams	15	20	24		do		10	70	Wind	D, S			75.00
Henry Heidsick	22	20	24		do	30	10	70	Hand	D, S		15	4.00
John Sobrest	23	20	24	1885	do	34	8	69	do	D, S		15	4.00
S. E. Wharton	16	20	24	1904	Bored, 10 inches	250	9.5		Gas	I	64	600	1,645.00
Mrs. J. M. Slinkard	26	20	24	1898	Bored, 8 inches	40	9		do	D, S		25	300.00
Van Lowman	27	20	24	1894	Bored, 6 inches	30	9	66	Hand	D, S		15	4.00
J. H. McFarland	27	20	24		do	80	9		Gas			280	
Do	27	20	24		do	60	9						
M. R. Lopes	27	20	24		Bored, 8 inches	48	8	67	Horse	D, S		35	15.00
J. H. McFarland	27	20	24	1891	Bored, 6 inches	52	10	66	Wind	D, S		50	75.00
Dr. Lewis	34	20	24		Bored, 10 inches		0	80	Artesian	I	a10		
H. H. Russell	34	20	24	1893	Bored, 5 inches	44	8	70	Wind	D, S		20	50.00
Henry Beatty	34	20	24		do	46	8.5	69	do	D, S		25	50.00
Sarah Phillips	32	20	24		Bored, 7 inches	1,000	0	72	Artesian	S	1		
Do	32	20	24		do		0	72	do	I	9		
California Savings & Loan Society	31	20	24		do		0	71	do	I	2		
R. Jones	30	20	24	1885	Bored, 6 inches	500	0	75	do	I, S	4		
W. A. Bailey	20	20	24	1902	Bored, 5 inches	75	9	68	Wind	D, S		37.50	50.00
O. W. Griffith	18	20	24	1899	do	80		69	Hand, wind	D, S		40	75.00
J. F. Haskell	19	20	24		do	23	10	72	Wind	D, S		10	75.00
B. Harrison	19	20	24		Bored, 7 inches		0	72	Artesian	I	9		
Page & Monteagle	13	20	23		do		0		do	I	a2		
J. Haskell	24	20	23		do	580?	0	71	do	I, S	Small.	1,000	
J. F. Chinn	25	20	23	1895	Bored, 4 inches	60	9	72	Wind	D, S		30	73.00
A. F. Stowe	25	20	23	1884	Bored, 8 inches	640	0	76	Artesian	I	11		
Page & Monteagle	14	20	23		do		0	74	do	I	6		
M. A. Quell	14	20	23		do		0	72	do	I	4		
John Crawford	26	20	23	1888?	Bored, 7 inches	400	0	72	do		Small.		
F. C. Hough	25	20	23		Bored, 9 inches	787	0	76	do	I	24		
Mrs. Trefry	26	20	23		Bored, 7 inches	300?	0	73	do	I	5		
P. F. Wood	35	20	23	1885	do	600	0	74	do		48		
Do	35	20	23		do	600	0		do	I	a30		
S. E. Hoffman	34	20	23	1890	Bored, 8 inches	500	0	73	do	D, S	Small.	1,000	
Do	34	20	23	1890	Bored, 9 inches	719	0		do	I	50	1,900	
S. F. Leckert	15	20	23		Bored, 8 inches	350?	0	73	do	S	2		
J. Hunlston	15	20	23	1900	Bored, 10 inches	130	10		Gas	I	88	165	1,100.00
Do	15	20	23		Bored, 5 inches	65	9		Wind	D, S		35	75.00
G. W. Gibson	22	20	23	1889?	Bored, 9 inches	418	0	73	Artesian	I, D, S	5	756	
Henry Girdlestone	22	20	23		Bored, 7 inches		0	74	do	I	6		
Henry Bertch	21	20	23	1903	Bored, 5 inches	60	12	70	Wind	D, S		30	75.00
Mrs. E. E. Beal	21	20	23	1899	Bored, 12 inches	140	10		Steam	I		180	220.00
Geo. H. Castle	21	20	23	1904	Bored, 10 inches	102	10		Gas	I		80	120.00
San Francisco Savings Union	28	20	23		Bored, 7 inches		0	72	Artesian	S	3		
Do	28	20	23	1882	do	521	0	74	do	D, S, I	7		

a Yield estimated or statement of owner taken.

b Three wells.

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TABLE 55.—*Records of wells in Tulare County*—Continued.

Owner.	Location.			Year completed.	Type and diameter of well.	Depth of well.	Depth to water level.	Temperature of water.	Method of lift.	Use of water.	Yield.	Cost of well.	Cost of machinery.
	Section.	Township south.	Range east.										
						Feet.	*Feet.*	°*F.*			*Miner's inches.*		
Wallace Bros.	32	20	23	.....	Bored, 8 inches....	530	0	74	Artesian.....	I.....	5	$600	.....
J. M. Sage	32	20	23	1903	Bored, 7 inches....	53	10	.....	Horse.....	I.....	.....	100	$650.00
San Francisco Savings Union	32	20	23	.....	Bored, 10 inches...	800	0	75	Artesian.....	I.....	29	.....	.....
Mr. Whitney	32	20	23	1904	Bored, 14 inches...	175	8	.....	Steam.....	.....	a 222	350	5,000.00
Do	32	20	23	1904	Bored, 10 inches...	868	0	76	Artesian.....	I.....	24	2,300	.....
H. B. Congdon	4	21	23	1888	Bored, 8 inches....	35	15	70	Wind.....	S.....	.....	35	50.00
F. W. Pursell	8	21	23	1905	Bored, 10 inches...	954	0	78	Artesian.....	I.....	40	2,500	.....
Artesia school district	8	21	23	.....	Bored, 5 inches....	42	11	70	Wind.....	D.....	.....	20	50.00
Mr. Anderson	3	21	23	1890	Bored, 8 inches....	900	0	75	Artesian.....	I.....	42	2,000?	.....
W. F. White	3	21	23	.....	.....do.....	750	0	74	.....do.....	I.....	24	.....	.....
J. R. Hascoe	10	21	23	1897	.....do.....	800	0	74	.....do.....	I.....	20	.....	.....
H. Kaiser	10	21	23	1887	.....do.....	778	0	75	.....do.....	I.....	38	2,000	.....
Chas. Blaswick	10	21	23	.....	Bored, 7 inches....	+500	0	74	.....do.....	I.....	4	.....	.....
J. & M. B. LaMarche	1	21	23	1882	.....do.....	390	0	71	.....do.....	I, S, D...	4	.....	.....
Do	6	21	24	.....	.....do.....	.....	0	70	.....do.....	I, S.....	8	.....	.....
Do	5	21	24	.....	Bored, 12 inches...	.....	0	70	.....do.....	I.....	9	.....	.....
W. Williams	8	21	24	.....	Bored, 8 inches....	38	10	70	Hand.....	S.....	.....	25	4.00
Do	8	21	24	.....	Bored, 7 inches....	.....	0	74	Artesian.....	I.....	4	.....	.....
Mrs. Smith	4	21	24	.....	.....do.....	.....	0	72	.....do.....	S, D.....	Small.	.....	.....
J. Goldman & Co	17	21	24	.....	.....do.....	41	9	60	Hand.....	S.....	.....	25	4.00
San Francisco Savings Union	16	21	24	.....	.....do.....	.....	0	74	Artesian.....	I.....	15	.....	.....
E. Lathrop	10	21	24	.....	Bored, 8 inches....	51	18	70	Wind.....	S.....	.....	40	50.00
D. B. Moore	15	21	24	.....	Bored, 7 inches....	.....	0	70	Artesian.....	I.....	7	.....	.....
Thomas Blades	35	20	24	.....	Bored, 5 inches....	26	3	66	Hand.....	D.....	.....	15	4.00
A. J. McKay	1	21	24	.....	.....do.....	50	12?	70	.....do.....	D, S.....	.....	25	4.00
Wm. James	11	21	24	1884	Bored, 6 inches....	60	10	.....	Horse.....	D, S.....	.....	30	20.00
Dr. Wilson	7	21	25	.....	Bored, 10 inches...	.....	0	.....	Artesian, gas.....	D, S.....	Small.	.....	.....
M. M. Janes	12	21	24	.....	Bored, 5 inches....	54	10	67	Wind.....	D, S.....	.....	30	75.00
R. C. Clark	18	21	25	1887	Bored, 7 inches....	51	14	.....	.....do.....	D, S.....	.....	50	75.00
T. J. Janes	14	21	24	1882	Bored, 8 inches....	400	0	.....	Artesian.....	.....	.....	621	.....
Sisson, Crocker & Co	8	21	25	1880	.....do.....	35	12	.....	Wind.....	D, S.....	.....	35	50.00
J. S. Futrell	9	21	25	1895	Bored, 5 inches....	50	12	68	Wind, horse.....	D, S.....	.....	40	65.00
W. Coughran	10	21	25	1891	Bored, 7 inches....	60	12	69	Horse.....	D, S.....	.....	40	50.00
Dresser Bros	17	21	25	1898	Bored, 8 inches....	121	14	}	Steam.....	I.....	a 122	90	1,000.00
Do	17	21	25	1898	.....do.....	56	14						
B. W. Blankenship	16	21	25	1890	Bored, 6 inches....	28	10	65	Hand.....	D.....	.....	15	4.00
Do	16	21	25	1900	Bored, 8 inches....	60	16	}	Gas.....	I.....	a 100	130	1,100.00
Do	16	21	25	1900	.....do.....	84	16						

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Do	16	21	25	1890	Bored, 5 inches	60?	12	68	Wind	D,S		30	50.00
Do	15	21	25	.....	....do	20	13	69	....do	D,S		15	50.00
John Ruppenthall	3	21	25	.....	Bored, 8 inches	.....	12	.....	Horse	S		.....	50.00
Sarope Gegargeion	11	21	25	.....	Bored, 5 inches	21	12	.....	Wind	D,S		10	50.00
P. N. Blankenship	10	21	25	1890	....do	60	12	66	....do	S		60	50.00
Linder Hardware Co	14	21	25	1898	Bored, 8 inches	26	15?	67	Hand	S		20	4.00
J. R. Blankenship	15	21	25	.....	Bored, 5 inches	24	11	69	Wind	D,S		12	50.00
Louis Jager	22	21	25	1891	Bored, 6 inches	40	12	70	....do	D,S		40	50.00
J. W. Martin	23	21	25	1905	Bored, 8 inches	60	13	.....	Steam	I	180	50	1,000.00
B. F. Vaughn	13	21	25	.....	Bored, 6 inches	75	12	68	Hand	D,S		40	4.00
Bennett Rising	11	21	25	.....	Bored, 5 inches	28	11.5	68	....do	S		15	4.00
H. H. Hannaford	2	21	25	1870	Bored, 8 inches	48	15	68	Wind	D,S		50	50.00
E. & L. Cornell	13	21	25	.....	Bored, 5 inches	26	9	66	Hand	D		15	4.00
Bigham estate	24	21	25	1888	Bored, 6 inches	32	7	70	Wind	D,S		18	100.00
R. H. Allen	8	21	26	1880	....do	33	6	68	....do	D,S		.....	.....
T. P. Carlisle	18	21	26	.....	Bored, 7 inches	38	6	70	Hand	D		.....	.....
W. W. Futrell	20	21	26	1893	Bored, 3 inches	31	7	70	....do	D		.....	.....
J. B. Monroe	17	21	26	1895	Bored, 5 inches	44	6	69	Wind	D		.....	.....
C. Otto	16	21	26	1891	....do	40	6	68	Hand	D		.....	.....
J. Vossler	21	21	26	1888	Bored, 6 inches	52	7	69	....do	S		.....	.....
J. Vincent	20	21	26	.....	Bored, 5 inches	38	6	70	....do	D,S		.....	.....
C. A. Ball	22	21	26	1894	Bored, 8 inches	30	7	68	Hand	D		.....	.....
J. Maples	14	21	26	1895	Bored, 5 inches	52	6	69	Wind	D,S		.....	.....
L. Griffin	23	21	26	.....	Bored, 4 inches	40	6	.....	....do	D,S		.....	.....
R. H. Dickey	23	21	26	1890	Bored, 5 inches	45	6	69	Hand	D		.....	.....
D. Udell	19	21	27	1892	....do	55	9	69	Wind	D,S		.....	.....
J. L. Miner	30	21	27	1896	Bored, 7 inches	49	9	67	....do			50	.....
B. Stadtmiller	30	21	27	1890	Bored, 6 inches	53	6	65	Hand	D,S		.....	.....
H. Quinn	31	21	27	.....	....do	47	6	66	....do	D		.....	.....
G. Caldwell	29	21	27	1898	Bored, 5 inches	52	5	69	....do	D		.....	.....
Burton school district	28	21	27	.....	....do	54	6	68	....do	D		.....	.....
M. A. Williams	33	21	27	1898	....do	40	.....	68	....do	D		.....	.....
G. Gregory	28	21	27	1898	....do	44	7	69	....do	D		.....	.....
W. Atkin	34	21	27	1892	....do	42	8	68	Wind	D,S		30	35.00
City of Portersville [b]	25	21	27	1901 1904	Bored, 12 inches	200	25	71	Electric	D,S	122	.....	.....
A. G. Schulz	25	21	27	1898	Bored, 11 inches	170	26	71	Gas	I	.....	250	.....
Mrs. W. M. Henry	25	21	27	1897	Bored, 12 inches	152	29	.....	Steam	.....	30	.....	.....
G. W. Smith	30	21	28	1900	Bored, 10 inches	85	12	.....	Gas	I	12	.....	.....
M. Davidson	30	21	28	1902	Bored, 12 inches	130	10	70	Electric	I	[a] 55	400	1,600.00
Do	29	21	28	1902	....do	102	27	71	....do	I	43	.....	1,600.00
Rosedale Water Co	3	22	28	1897	Dug	23	6	70	....do	I	43	150	1,000.00
C. D. Boydston	3	22	28	1904	Bored, 12 inches	190	22	72	....do	I	[a] 70	600	4,000.00
Do	10	22	28	1904	....do	100	24	71	[c]	S	[c]	250	.....
Mrs. R. A. Henderson [d]	4	22	28	1904	....do	60	12	70	Electric	I	[a] 60	.....	.....
W. H. McCain	6	22	28	1901	Bored, 10 inches	120	65	.....	....do	I	[a] 8	240	600.00
Frame Bros	1	22	27	1901	....do	144	43	74	....do	I	16	.....	.....
C. Talbott	1	22	27	1902	Bored, 12 inches	194	8	.....	....do	I	[a] 18	270	1,000.00
P. Ting	1	22	27	1901	Bored, 10 inches	160	38	74	....do	I	9	500	600.00
C. Sullivan	12	22	27	1904	Bored, 12 inches	205	63	72	....do	I	[a] 37	.....	.....

[a] Yield estimated or statement of owner taken.
[b] Two wells.
[c] Tapped below surface; flow 13 miner's inches.
[d] Five wells.

8925°—wsp 396—16——18

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TABLE 55.—*Records of wells in Tulare County*—Continued.

Owner.	Location.			Year completed.	Type and diameter of well.	Depth of well.	Depth to water level.	Temperature of water.	Method of lift.	Use of water.	Yield.	Cost of well.	Cost of machinery.
	Section.	Township south.	Range east.										
						Feet.	*Feet.*	°*F.*			*Miner's inches.*		
C. J. Swartz	10	22	27	1901	Bored, 6 inches	60	33	73	Wind	D, S		$42	$60.00
C. Bastain	9	22	27	.....	....do	51	30	72	....do	D, S		.....	.....
J. W. Hockett	34	21	27	1895	Bored, 2 inches	36	7	68	Hand	D		.....	.....
G. Anthony	4	22	27	1890	Bored, 6 inches	35	9	69	Wind	D, S		.....	.....
G. B. Moore	8	22	27	.....	....do	38	14	69	....do	D, S		.....	.....
V. A. Stewart	7	22	27	1887	....do	47	16	69	....do	D, S		.....	.....
Mrs. M. Florey	31	21	27	1884	Bored, 5 inches	45	6	67	Hand	D		.....	.....
C. Bour	31	21	27	1896	....do	34	6	69	Wind	D, S		.....	.....
F. W. Howell	6	22	27	.....	....do	38	8	70	....do	D, S		.....	.....
U. M. Ferguson	1	22	26	1904	Bored, 12 inches	52	9	70	Gas	I		.....	.....
J. M. Ferguson	2	22	26	.....	Bored, 5 inches	34	9	69	Hand	D		.....	.....
J. E. Henderson	25	21	26	1885	Bored, 7 inches	60	6	67	Wind	D, S		.....	.....
E. R. Buxton	26	21	26	.....	Bored, 4 inches	64	7	70	....do	D		65	.....
S. Vincent	26	21	26	1902	....do	28	8	71	....do	S		18	.....
S. J. Vincent	27	21	26	1886	Bored, 5 inches	75	8	.....	....do	S		54	.....
H. Quinn	27	21	26	.....	....do	44	8	70	....do	D, S		.....	.....
F. Carlisle	27	21	26	1890	....do	25	8	70	....do	D		15	.....
A. E. Scruggs	28	21	26	1892	Bored, 6 inches	64	9	71	Horse	D, S		47	.....
U. F. Woods	35	21	26	1905	Bored, 16 inches	170	16	69	.....	.....		.....	.....
V. A. Stewart	34	21	26	1890	Bored, 5 inches	38	10	70	Wind	D, S		30	.....
M. Dale	4	22	26	.....	Bored, 4 inches	40	13	69	....do	D, S		.....	.....
M. Gilligan	29	21	26	1895	Bored, 6 inches	70	10	.....	....do	D, S		.....	.....
Do	29	21	26	1895	....do	75	10	.....	Hand	D		75	.....
Do	30	21	26	1885	....do	75	10	70	....do	D		75	.....
G. J. Herndon	32	21	26	.....	Bored, 7 inches	33	13	70	....do	S		.....	.....
G. J. Martin	32	21	26	.....	Bored, 6 inches	30	11	70	Wind	S		.....	.....
T. J. Allen	24	21	25	1893	....do	75	10	68	Hand	D		40	4.00
E. Z. Callison	26	21	25	1870	Bored, 8 inches	70	10	65	....do	D, S		100	25.00
L. N. Callison	2	22	25	1885	Bored, 5 inches	60	20	72	....do	S, D		45	12.00
Mrs. G. Montgomery	4	22	25	1887	Bored, 8 inches	60	18	70	Horse	D, S		33	12.00
Mrs. A. B. McNeil	4	22	25	1895	Bored, 6 inches	60	23	.....	Wind	D, S		35	50.00
W. H. Crowley	5	22	25	1904	Bored, 10 inches	72	25	.....	Gas	I	[a] 300	72	1,700.00
Do	5	22	25	.....	Bored, 8 inches	76	22	72	Wind	D, S		60	75.00
Mrs. A. Treybal	5	22	25	.....	Bored, 7 inches	34	24	70	....do	D, S		20	75.00
John Clark	32	21	25	.....	....do	35	19	70	....do	S		20	50.00
G. E. Gibb	20	21	25	1905	Bored, 8 inches	67	15	70	Horse	I		58	80.00
Dresser & Smith	19	21	25	1904	Bored, 12 inches	92	13	.....	Gas	I	[a] 100	150	1,385.00
T. J. Janes	24	21	24	.....	Bored, 7 inches	50	18	68	Wind	S		30	4.00

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F. Jordan	24	21	24	1885	Bored, 4 inches	255	16.5		do	D, S		13	50.00
E. W. Bagby	25	21	24	1899	Bored, 10 inches	80	16		Gas	I	a150	80	1,120.00
Mrs. A. Treybal	31	21	25	1888	Bored, 5 inches	93		69	Hand	D, S		45	4.00
Mrs. N. G. Rice	6	22	25	1902	Bored, 8 inches	60	23		Wind	D, S		80	75 00
H. J. Hawkins	2	22	24		do		1		do	S			50.00
Mrs. L. L. Creech	26	21	24	1887	Bored, 7 inches	600	0	72	Artesian	I	2	1,000	
L. B. Retherford	24	21	24	1899	Bored, 5 inches	29	14	69	Hand	D		32	4.00
Mrs. J. Mead	23	21	24	1884?	Bored, 7 inches		0	70	Artesian	I	4	800	
Chas. Dresser	26	21	24		do	33	11	67	Horse	D, S		20	40.00
T. J. Mitchell	27	21	24	1882	do	355	0	70	Artesian	I, D	12		
F. M. Creech	34	21	24	1896	Bored, 8 inches	64	14		Gas	I		90	1,200.00
Do	34	21	24	1896	do	72	14						
School district	3	22	24		Bored, 7 inches	52	16		Wind	D		35	50.00
S. A. Nickols	2	22	24	1893	do	50	17	69	do	S		60	50.00
San Francisco Savings Union	2	22	24		do		0	74	Artesian	I	2		
T. J. Mitchell	3	22	24	1889	do	825	0		do	I	12	2,200	
Mrs. Elsie Beckwith	4	22	24	1883	do	410	0	73	do	I, D, S	7	414	
H. H. Beckwith	4	22	24	1890?	Bored, 8 inches	600	0	72	do	I	12	900	
Wm. Swall	23	21	24		do	500	0	70	do	I	5		
Mrs. Smith	28	21	24	1890	Bored, 7 inches	400	0	72	do	I	7	600	
Wm. Swall	27	21	24	1905	Bored, 10 inches	87	14		Steam	I	a150	50	2,300.00
B. Gulley	22	21	24	1875	Dug, 4 by 4 feet	20	15	68	Wind	S		20	30.00
Wm. Swall	28	21	24		Bored, 10 inches	350	0	70	Artesian	I	11		
Elk Bayou school district	29	21	24		Bored, 5 inches	50	12		Wind	D		30	50.00
Evans Bros	20	21	24	1891	do	50	12		do	N		25	
J. H. Finney	29	21	24	1883	Bored, 7 inches	500	0	72	Artesian	I	9	1,000	
Do	29	21	24		Bored, 6 inches	50	12		Wind	S		25	50.00
W. J. Estes	32	21	24	1880	Bored, 5 inches	30	11		do	D, S		15	25.00
D. K. Berry	31	21	24	1874	Bored, 7 inches	30	17	69	do	D, S		25	25.00
Do	31	21	24	1885	Bored, 8 inches	630	0	71	Artesian	I	5	1,200	
M. A. Edgar	6	22	24		do		0	73	do	I	6		
Cosmos Land & Water Co	5	22	23		Bored, 7 inches	34	14.5		Horse	I		100	125.00
Geo. Harrison	31	21	23		Bored, 8 inches	350	0	74	Artesian	D, S	a2		
C. H. Sherwin	7	22	23	1898	Bored, 2 inches		0	69	do	D, S	Small.	174	
A. V. Taylor	17	22	23		Bored, 12 inches	815	0	76	do	I	30		
Do	17	22	23		Bored, 8 inches	918	0	78	do	D, S, I	78		
Mr. Quimby	19	22	23		Bored		0	74	do	D, I, S	a5		
S. Mitchell	21	22	23		Bored, 7 inches	800	0	78	do	I, D, S	56		
F. A. Thompson	30	22	23	1893	Bored, 9 inches	1,000	0	81	do	I, S, D	76	3,000	
Do	30	22	23	1905	Bored, 4½ inches	1,200	0	77	do	I	30	1,080	
F. M. Parrish	29	22	23		Bored, 10 inches	700	1	68	Hand	D, S		1,050	10.00
C. Curry	29	22	23		Bored, 7 inches		0	72	Artesian	D, S	2		
A. Watts	29	22	23		Bored, 9 inches	830	0	76	do	I			
H. W. Butcher	27	22	23		Bored, 12 inches	50	10	68	Wind	D, S		50	275.00
J. Goldman	8	22	24		Bored, 5 inches	56	12		Not raised	N		55	
Seth Kirby	8	22	24	1886	Bored, 9 inches	606	0	70	Artesian	I	16	1,300	
Lakeview school district	8	22	24	1884	Bored, 5 inches	50	11		Wind	D		50	40.00
Mrs. Elsie Beckwith	8	22	24		do	46	12		do	S		45	50.00
F. J. Hesse	20	22	24	1887	Bored, 8 inches	606	0	70	Artesian	I	24	1,240	
Mr. Mansky	9	22	24		do		0	69	do	I	24		

a Yield estimated or statement of owner taken.

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TABLE 55.—*Records of wells in Tulare County*.—Continued.

Owner.	Location. Station.	Township south.	Range east.	Year completed.	Type and diameter of well.	Depth of well.	Depth to water level.	Temperature of water.	Method of lift.	Use of water.	Yield.	Cost of well.	Cost of machinery.
						Feet.	*Feet.*	°F.			*Miner's inches.*		
F. J. Crane	10	22	24	1884	Bored, 5 inches	435	0	69	Artesian	S			
Robert Doran	10	23	24	1884	Bored, 8 inches	480	0	69	do	I	13	$900	
A. D. Evans	10	22	24		do	68	18	67	Steam	I	a 133	150	$1,400.00
						76	18	67					
Mrs. C. Ranger	22	22	24	1887?	do	600	0	70	Artesian	I	16		
Do	22	22	24	1893	Bored, 14 inches	1,400	0	71	do	I	5	6,000	
H. C. Grigsby	22	22	24	1885	Bored, 7 inches	450	0	69	do	I	3		
Fred Hesse	26	22	24		Bored, 8 inches	+400	0	68	do	I	11	900	
R. H. Copeland	26	22	24	1905	do	78	15		Steam	I		200	210.00
						102	15						
Frank Laughlin	24	22	24	1896?	do	500	0	70	Artesian	I	18		
J. Ranger	24	22	24		Bored, 7 inches		0	69	do	S	3		
Wm. Budd	23	22	24		Bored, 10 inches	1,100	0	70	do	I	36	2,700	
J. J. Ryan	13	22	24	1886	Bored, 9 inches	1,043	0	72	do	I	3		
B. C. Treefry estate	18	22	25		Bored, 7 inches	400	3		Not raised	N			
Do	14	22	24		do		1		do	N			
A. N. Towne Co	12	22	24		do		0	72	Artesian	S	Small.		
Do	7	22	25		Bored, 8 inches	400?	3		Hand	N			5.00
W. J. Coles	20	22	25	1887	Bored, 5 inches	65	16		Wind	D, S		40	100.00
Robert McDaniel	22	22	25	1905	do	26	18	67	do	S		15	65.00
W. J. Browning	10	22	25	1901	Bored, 14 inches	84	32		Steam?	I			
S. D. Luck	23	22	25	1904	Bored, 5 inches	31	15		Wind	I		29	15.00
S. B. Garrett	4	22	26	1902	Bored, 6 inches	30	14	70	Hand	D			
J. Murphy	4	22	26		Bored, 4 inches	29	14	70	do	D			
E. A. May	10	22	26		Bored, 5 inches	45	12	71	Wind	D			
E. Saak	11	22	26		do	31	15	71	do	S		20	
E. L. Cloer	15	22	26	1904	Bored, 10 inches	48	16		Gas	I	60		
J. Fine	22	22	26		Bored, 5 inches	54	17	71	Wind	D, S		40	
J. Vincent	21	22	26		Bored, 6 inches	35	18		do	S			
C. N. Thomas	14	22	26	1899	Bored, 5 inches	42	15	71	do	D, S			
A. Hayes	12	22	26		Bored, 6 inches	50	22	73	do	D, S			
E. L. Cloer	24	22	26		Bored, 5 inches	43	21	69	do	D, S			
Mr. Chinn	17	22	27	1905	Bored, 7 inches	48	40		Not raised	N			
Hope school district	16	22	27	1890	Bored, 8 inches	52	40		Wind	D			
J. Kambich	11	22	27	1888	Bored, 6 inches	61	53	71	do	D, S			
D. Abbott	14	22	27	1893	do	+100	72	72	do	D			
D. Sturm	12	22	27	1903	Bored, 12 inches	240	60	73	Electric	I	a 18	600	1,400.00
A. Sauerwein	18	22	28	1904	do	197	58	71	do	I	14	500	

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M. C. Thompson	18	22	28	.....	Bored, 6 inches	140	67	69	Wind	D, S	.....	.....	.....
H. Mentz	20	22	28	.....	Bored, 7 inches	112	32	69	Horse	D, S	.....	.....	.....
A. Konda	4	23	28	1902	....do	200	120	.....	....do	D, S	.....	.....	.....
L. W. Howeth	26	23	28	.....	Dug, 4 by 4 feet	53	38	.....	Wind	D	.....	.....	.....
J. B. Dennis	30	23	28	1893	Bored, 6 inches	98	64	71	....do	D, S	.....	.....	.....
Hall, Brownell & Myers	23	23	27	1889	Bored, 7 inches	150	105	.....	Horse	S	.....	.....	.....
Higgins & Tyler	14	23	27	.....	....do	126	84	.....	Wind	D, S	.....	.....	.....
M. Davidson	2	23	27	.....	Bored, 6 inches	98	88	70	....do	D, S	.....	.....	.....
Salem school district	3	23	27	.....	....do	110	81	70	....do	D	.....	.....	.....
J. F. Blair	4	23	27	1886	Bored	92	90	72	Horse	D, S	.....	.....	.....
J. E. Porch	8	23	27	1889	Bored, 7 inches	100	87	71	Wind	D, S	.....	.....	.....
R. Porch	8	23	27	1890	....do	104	89	71	....do	D, S	.....	.....	.....
Mrs. M. S. McCapes	6	23	27	1887	Bored, 6 inches	84	56	71	Wind and hand	D, S	.....	.....	.....
M. E. Galbraith	6	23	27	.....	....do	72	50	71	Wind	D, S	.....	.....	.....
A. J. Salladay	12	23	26	.....	Bored, 7 inches	79	51	.....	....do	D, S	.....	.....	.....
Tulare County	30	22	27	1900	Bored	35	23	68	Hand	S	.....	35	.....
J. McNeil	26	22	26	1885	Bored, 6 inches	.....	25	.....	Wind	D, S	.....	.....	.....
L. Shoenfeld	27	22	26	.....	Bored, 5 inches	50	17	69	....do	D, S	.....	.....	.....
M. Cottle	28	22	26	1887	....do	64	18	70	....do	D, S	.....	65	.....
J. Vincent	32	22	26	.....	Bored, 6 inches	74	18	.....	....do	S	.....	75	.....
J. C. Tilton	4	23	26	1902	Bored	65	35	68	....do	D, S	.....	45	80.00
W. W. Salladay	10	23	26	1885	Bored, 5 inches	50	35	69	....do	D, S	.....	.....	.....
D. Williams	8	23	26	1887	Bored, 6 inches	30	27	72	....do	D	.....	25	70.00
S. I. Vincent	6	22	26	1891	....do	72	19	70	....do	D, S	.....	.....	.....
E. N. Brushwood	12	23	26	1893	Bored, 8 inches	90	20	67	Horse	S	.....	.....	.....
G. W. Doran	10	23	25	1885	Bored, 7 inches	80	18	71	Wind	D, S	.....	.....	.....
J. Gable	2	23	25	.....	Bored, 4 inches	62	26	67	....do	D, S	.....	.....	.....
E. J. Elster	34	22	25	1885	....do	40	24	70	....do	D	.....	.....	.....
Wm. Gable	35	22	25	1890	Bored, 8 inches	26	18	.....	....do	.....	.....	25	40.00
J. T. Luck	34	22	25	1887	Bored, 5 inches	28	16	.....	....do	S	.....	28	65.00
J. M. Falling	34	22	25	1901	Bored, 7 inches	60	16	.....	Horse	D, S	.....	50	100.00
J. E. Falling	34	22	25	1891	Bored, 5 inches	40	16	.....	Wind	S	.....	30	65.00
R. T. Priest	3	23	25	.....	Bored, 8 inches	600	.....	66	....do	S	.....	.....	.....
Do	3	23	25	1883	....do	680	.....	76	....do	S	.....	.....	.....
G. W. Smith	10	23	25	1892	Bored, 7 inches	99	24	70	....do	S, D	.....	80	150.00
S. S. Huston	14	23	25	1887	....do	.....	16	69	....do	S	.....	.....	.....
H. E. Phillips	14	23	25	.....	....do	.....	16	.....	Not raised	N	.....	.....	.....
J. A. Peck	30	22	25	.....	Bored, 8 inches	.....	0	72	Artesian	I	a 5	.....	.....
D. F. Retherford	29	22	25	1886	....do	24	18	.....	Wind	D, S	.....	25	40.00
W. A. Lythe	32	22	25	.....	....do	750?	0	72	Artesian	I	Small.	1,600	.....
J. W. Harper	32	22	25	.....	....do	.....	0	78	....do	S	9	.....	.....
P. Slowey	7	23	25	1890	....do	500	0	78	....do	I	8	.....	.....
Mrs. L. Hefty	7	23	25	1890	Bored, 9 inches	800	0	77	....do	I	3	800	.....
N. C. Cross	8	23	25	1903	Bored, 6 inches	30	16	64	Wind	D, S	.....	30	20.00
W. B. Bradbury	8	23	25	1895	Bored, 8 inches	1,387	0	79	Artesian	I	40	.....	.....
J. Manuel	18	23	25	1883	Bored, 9 inches	500	0	76	....do	S	3	.....	.....
D. Abrate	18	23	25	1883	Bored, 6 inches	14	12	63	Hand	D	.....	.....	.....
W. Dougherty	14	23	24	1903	Bored, 7 inches	100	16	65	Wind	D, S	.....	.....	.....
Towne ranch	11	23	24	.....	Bored, 9 inches	1,142	0	80	Artesian	I	.....	.....	.....
Do	11	23	24	.....	....do	815	0	70	....do	I	.....	.....	.....
Do	11	23	24	.....	....do	1,000	0	78	....do	I	.....	.....	.....

a Yield estimated or statement of owner taken.

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TABLE 55.—*Records of wells in Tulare County*—Continued.

Owner.	Location.			Year completed.	Type and diameter of well.	Depth of well.	Depth to water level.	Temperature of water.	Method of lift.	Use of water.	Yield.	Cost of well.	Cost of machinery.
	Section.	Township south.	Range east.										
						Feet.	*Feet.*	°*F.*			*Miner's inches.*		
Mrs. M. H. Smith	2	23	24	1883	Bored, 8 inches	550	0	74	Artesian	I.	23	$1,000	
L. E. Smith	36	22	24	1904	Bored, 4 inches	80	16	70	Gas	I.	50	200	$1,600.00
San Francisco Savings Union	36	22	24		Bored, 9 inches	+700	0	70	Artesian	I.			
Mrs. A. J. Merchant	35	22	24	1888	Bored, 8 inches	900	0	70	do	I.	11	3,000	
J. S. Copland	26	22	24		Bored, 5 inches	28	12		Horse	D, S.		30	50.00
W. H. Howard	34	22	24	1888	Bored, 9 inches	582	0	75	Artesian	I.	18	1,200	
San Francisco Loan & Savings Bank	3	23	24	1883	Bored, 8 inches	600	0	74	do	S.	32		
Do	3	23	24	1891	Bored, 9 inches	+800	0	78	do	I.	58		
Do	33	22	24	1887	do	+600	0	78	do	S, I.	58		
J. Black	9	23	24	1890	Bored, 10 inches	1,000	0	78	do	I, S, D.	76	3,000	
Do	16	23	24	1890	do	1,100	0	80	do	S.	205	4,000	
L. P. Chittenden	7	23	24	1890	do	+700	0	77	do	I.	52		
Do	7	23	24	1890	do	+700	0	78	do	I.	58		
M. C. Meeker	5	23	24		Bored, 5 inches	+500	0	76	do	S.			
L. P. Chittenden	6	23	24		do		0	77	do	S.	13		
W. H. Harp	3	23	23	1905	Hydraulic, 5½ inches.	1,103	0	78	do	I.	42		
P. D. Brudaker	3	23	23	1904	Hydraulic, 4 inches	1,025	0	78	do	I.	19	800	
Do	3	23	23	1904	Bored, 2 inches	355	0	70	do	D.	Small.	160	
W. H. Harp	3	23	23	1905	Hydraulic, 4 inches	345	0	71	do	D, S.	Small.		
T. G. McGinnis	5	23	23		Hydraulic, 2 inches		0	72	do	S.	Small.		
W. A. Sage	8	23	23		do		0	70	do	D, S.			
E. L. Kauffman	9	24	23		Bored, 8 inches		0	76	do	I, D, S.			
L. G. Grosse	21	24	23		Bored		0		do	S.	Small.		
Crocker estate	32	24	24		Bored, 10 inches		0	70	do	N.	134		
Frank Smith	28	24	23		Bored, 8 inches		0	70	do	N.	Small.		
Mr. McCord	29	24	24		do		0	72	do	I.	22		
W. E. Brown	28	24	24		do		0		do	N.	a 8		
D. T. Curtis	22	24	24		Bored, 6 inches		0	71	do	N.	Small.		
D. R. Hughes	28	23	25		Bored, 8 inches	68	30†		Wind	S.		70	125.00
J. D. Fraser	32	23	25		Bored, 7 inches	50	14		do	D, S.		50	100.00
	33	23	25		Bored, 10 inches	1,300	0	75	Artesian	I.	22		
W. O. Goldman	34	23	25	1893	Bored, 7 inches	+60	21	60	Wind	D.			
S. S. Heasa	34	23	25	1886	do	42	25	58	do	D.		42	95.00
L. Bearce	26	23	25		Bored, 10 inches	106	27	69	Gas	I.	88	320	1,900.00
Do	26	23	25		do	93	27	69					
W. H. Haroldson	2	24	25	1893	Bored, 7 inches	55	35		Not raised	N.			
J. Martens	2	24	25	1903	do	58	40		do	N.			

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W. H. Haroldson	2	24	25	1893	Bored, 9 inches	70	40	.....	do	N	.....	.....	.....	.....
Do	10	24	25	1885	Bored, 7 inches	50	30	.....	Wind	D, S	.....	50	165.00	
J. D. Fraser	4	24	25	.....	Bored, 5 inches	50	15	.....	do	S	.....	50	45.00	
M. L. Nichols	22	24	25	1890?	Bored, 8 inches	60	25	.....	Gas	I	88	60	1,000.00	
C. W. Turner	28	24	25	1900	Bored, 10 inches	75	20	.....	do	I	44	.....	[b] 800.00	
A. Panero	26	24	25	1890	Bored, 6 inches	89	40	68	Wind	.....	.....	.....	.....	.....
J. W. Hamilton	24	24	25	.....	Bored, 8 inches	70	40	70	do	.....	.....	.....	.....	.....
Chas. Rieck	24	24	25	1887	Bored, 7 inches	57	45	.....	do	S	.....	60	90.00	
Do	18	24	26	1882?	Bored, 5 inches	56	52	.....	do	D, S	.....	55	90.00	
Do	18	24	26	1887	Bored, 7 inches	71	61	.....	Not raised	N	.....	70	.....	
Mr. Pinney	18	24	26	.....	do	62	52	.....	Wind	N	.....	60	150.00	
Charles Rieck	6	24	26	.....	Bored, 8 inches	62?	51	.....	do	S	.....	.....	125.00	
Frank Schlitz	6	24	26	1902	Bored, 10 inches	75	50	65	Gas	I	100	300	1,700.00	
L. Bearce	6	24	26	1887	Bored, 7 inches	54	35	62	Wind	D, S	.....	.....	125.00	
Do	5	24	26	.....	do	60	45	.....	Hand	S	.....	.....	.....	
H. B. Razey	20	23	26	1889	do	60	40	68	Wind	D, S	.....	.....	.....	
J. Jackson	22	23	26	1887	Bored, 5 inches	90	80	66	do	D, S	.....	60	.....	
A. Child	2	24	26	1887	Bored, 7 inches	111	100	56	do	D, S	.....	113	230.00	
Mr. Comstock	35	23	26	1890	do	115	100	58	do	S	.....	.....	.....	
Lockridge & Turner	34	23	26	1904	do	100	80	63	do	.....	.....	100	.....	
C. L. Pinney	8	24	26	1888	Bored, 8 inches	78	67	.....	do	D, S	.....	80	150.00	
W. H. Haroldson	9	24	26	.....	do	120	67	.....	do	S	.....	120	.....	
J. H. Cox	20	24	26	1889	Bored, 6 inches	80	60	.....	do	D, S	.....	80	180.00	
Wildflower school district	16	24	26	1890	Bored, 7 inches	100	85	.....	do	D	.....	100	75.00	
A. Sheppard	20	24	26	1904	do	82	56	60	do	D, S	.....	80	145.00	
J. Cox	30	24	26	1895	do	100	60	65	do	D, S	.....	100	75.00	
Mrs. L. C. Martin	30	24	26	1887	do	100	74	60	do	D	.....	75	100.00	
P. Shanahan	30	24	26	1897	do	90	60	60	do	D	.....	50	167.00	
C. Willard	32	24	26	1894	Bored, 6 inches	118	89	58	do	D, S	.....	80	155.00	
J. Panetto	32	24	26	1885	do	110	100	61	do	D, S	.....	85	.....	
J. Hedrick	34	24	26	1890	Bored, 7 inches	140	130	64	do	D, S	.....	.....	.....	
Mr. Reba	28	24	26	.....	do	100	70	.....	Not raised	N	.....	.....	.....	
W. H. Haroldson	21	24	26	.....	do	100	75	.....	Horse	N	.....	.....	.....	
B. Edwards	14	24	26	1887	do	100	96	.....	do	D	.....	100	75.00	
W. H. Harrison	15	24	26	1901	Bored, 8 inches	114	100	.....	do	S	.....	80	50.00	
Joe Fore	22	24	26	.....	do	120	90	.....	Wind	S	.....	120	226.00	
W. F. Burum	22	24	26	1887	do	100	92	.....	do	D	.....	100	226.00	
P. F. McDevitt	26	24	26	1892	Bored, 7 inches	146	140	70	do	D, S	.....	140	186.00	
H. P. Burum	26	24	26	1888	do	164	158	74	do	D, S	.....	100	115.00	
Mr. Bryant	34	24	26	1885	do	147	.....	.....	.....	.....	.....	.....	.....	
W. L. Smith	24	24	26	.....	.....	146	138	.....	Wind, horse	S	.....	150	175.00	
W. H. Haroldson	11	24	26	.....	Bored, 7 inches	140	120	.....	Horse	D, S	.....	140	100.00	
W. E. Welch	12	24	26	.....	do	146	122	.....	Wind	D, S	.....	171	229.00	
B. McCracken	6	24	27	1887	Bored, 6 inches	155	140	.....	do	S	.....	.....	.....	
W. K. Braly	32	23	27	1886	do	162	140	68	do	D, S	.....	150	270.00	
A. Welch	28	23	27	1887	do	150	140	68	do	D, S	.....	.....	.....	
F. M. Carlisle	28	23	27	1890	Bored, 7 inches	175	145	66	do	D	.....	.....	.....	
Braly Bros	33	23	27	1887	do	160	140	67	do	S	.....	150	.....	
Do	34	23	27	1887	Bored, 6 inches	200	170	.....	Not raised	N	.....	.....	.....	
A. J. Hall	35	23	27	1898	Bored, 7 inches	250	196	.....	Horse	S	.....	.....	.....	

[a] Yield estimated or statement of owner taken.

[b] Cost of well and equipment combined.

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TABLE 55.—*Records of wells in Tulare County*—Continued.

Owner.	Location.			Year completed.	Type and diameter of well.	Depth of well.	Depth to water level.	Temperature of water.	Method of lift.	Use of water.	Yield.	Cost of well.	Cost of machinery.
	Section.	Township south.	Range east.										
						Feet.	*Feet.*	°*F.*			*Miner's inches.*		
W. L. Smith	4	24	27	.....	Bored, 7 inches	130	120	62	Wind	D	.....	$225	$150.00
E. Zimmerman	28	24	27	.....	Bored, 8 inches	160	135	.....	....do	D, S	.....	160	150.00
John Crangle	8	24	27	.....	Bored, 7 inches	160	135	.....	....do	D, S	.....	160	175.00
P. Phillips	29	24	27	1890	....do	200	190	.....	Wind, horse	S	.....	.....	.....
Neil Beaton	28	24	27	.....	....do	244	190	.....	Wind	D, S	.....	350	225.00
John Collins	26	24	27	.....	....do	225	215	.....	....do	D, S	.....	225	125.00
Mrs. E. Zimmerman	11	24	27	.....	Bored, 8 inches	61	32	.....	....do	D, S	.....	60	200.00
Do	11	24	27	.....	....do	71	29	.....	Not raised	N	.....	70	.....
C. Menney	12	24	27	1890	.....	40	8	.....	Wind	D, S	.....	.....	.....
H. C. Castor	12	24	27	1890	Bored, 8 inches	84	40	.....	Horse	D, S	.....	.....	.....
N. H. Kelly	12	24	27	1890	....do	84	40	70	Wind	D, S	.....	84	85.00
W. O. Todd	18	24	28	1875	Dug, 4 by 4 feet	18	14	.....	Horse	S	.....	50	50.00
J. Menney	8	24	28	.....	Dug	20	9	.....	....do	D, S	.....	.....	.....
Joseph Miller	4	24	28	1894	Bored, 8 inches	200	190	.....	Wind	D	.....	200	7200.00
Pacific Coast Oil Co	19	23	24	1904	Bored, 10 inches	726	0	.....	Artesian	B	4	.....	.....

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KINGS COUNTY.

GENERAL CONDITIONS.

The valley portion of Kings County includes the present and past Tulare Lake bottoms and the southern slope of the lower Kings River delta. Tulare basin is the lowest point in the southern section of the valley and is the area in which all surplus waters from Kings River southward accumulate. The flood waters of Kings River are divided on its delta, part of them flowing northward to join the San Joaquin drainage, while the other part flows into Tulare Lake. During years of low or moderate snowfall and rainfall in the Sierra, practically all the flow of Kern, Tule, Kaweah, and Kings rivers is used in irrigation, and there is but little excess to escape to the basin; but during years of heavy precipitation great volumes of water accumulate in the Tulare lowlands. This basin is very shallow. Its shores have gentle slopes, hence the area of the lake fluctuates widely with slight changes in the depth of the water in it. Since settlement began in the San Joaquin Valley it has had a complex history. What is known of its earlier history has been summarized by Grunsky.[1] That part of the following résumé which deals with conditions prior to 1897 is condensed from his account; the résumé of conditions since 1907 has been furnished by H. D. McGlashan, district engineer, U. S. Geological Survey.

Résumé of history of Tulare Lake.[2]

1853. High.
1853–1861. Subsidence; elevation of surface in 1861, 204 feet above sea level.
1861–1863. Rapid rise to the highest known stage, 220 feet above sea level, overflowing into San Joaquin River; area about 800 square miles.
1863–1867. Decline to about 208 or 209 feet above sea level.
1867–1868. Filled again to about 220 feet above sea level.
1872–1876. Fluctuated between 211 and 217 feet above sea level.
1876–1883. Decline to 192 feet above sea level; lowest stage then known.
1883–1897. Fluctuating; generally low.
1897–1905. Decline; practically dry in 1898; dry in autumn of 1905.
1905–1907. Rise; elevation of water surface in summer of 1907, 193 feet above sea level; area of water surface, November, 1907, 274 square miles.[3]
1907–1908. Depth gradually decreasod from 14 feet in June, 1907, to 8.3 feet in December, 1908.
1909–1911. Gradual rise to depth of 13.4 feet in July, 1909; change in stage gradual to December, 1911, when depth was 10 feet.
1912–1913. Precipitation low. Depth gradually decreased to 1.5 feet in September, 1913.

[1] Grunsky, C. E., Irrigation near Bakersfield, Cal.: U. S. Geol. Survey Water-Supply Paper 17, pp. 16-17, 1898. Out of print; may be consulted in libraries.

[2] Elevation of bottom of lake, 179.1 feet above sea level.

[3] McGlashan, H. D., and Dean, H. J., Stream measurements in San Joaquin River basin: U. S. Geol. Survey Water-Supply Paper 299, p. 20, 1912.

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A knowledge of the history of this lake makes clear the origin and character of the soils of all except the northern part of Kings County, where the alluvial-fan or "delta" conditions so general in San Joaquin Valley prevail.

Evidences of the former occupancy of the lowlands by the lake appear everywhere. Faintly marked sandy beaches encircle the depression at various elevations and over these beaches are strewn the shells of the mollusks that lived in the lake. In its lowest parts, dry and planted in grain in 1905, the fine sediments that settled in the lake bottom make a fertile alluvial soil.

It is to be presumed that the history of the lake for many centuries has been like that part of it which we know directly, i. e., that it has fluctuated in area and depth, occasionally drying out completely, then filling to the point of overflow. Under such conditions relatively little of the water which it has contained can have escaped by surface overflow; the greater part of it has evaporated or has been absorbed by the sands and silts of the lake bottom.

With the shrinking of the lake during the years preceding the inflow of 1906, its old floor was placed under cultivation and valuable crops of grain were produced. This successful grain culture proves the nonalkaline character of the present surface of the old lake bottom, but the saline waters yielded by numerous shallow flowing wells within it indicate the presence of alkali at slight depths. The few wells available as evidence in and about the borders of the old lake, however, indicate that deeper wells in some places obtain the better water.

FLOWING WELLS.

There are probably as yet less than 100 flowing wells in Kings County (77 were visited by Geological Survey representatives in 1905), yielding approximately 20 second-feet. Probably not more than one-third of the wells are used for irrigation, a large number of small-bore shallow wells being used for stock and for domestic supply. The northern part of the county, in the vicinity of Hanford, Armona, and Lemoore, is well supplied with surface water by the canal systems that head in Kings River, and is a most productive, thoroughly cultivated area. Ground waters are not needed and no serious attempt has been made to utilize them here.

In the vicinity of Corcoran, Waukena, and Angiola, however, a successful colony has been established that depends almost entirely upon ground waters. A number of deep wells have been put down to depths of 900 to 1,600 feet, which yield flowing waters in amounts ranging from 5 to 40 miner's inches. Shallow wells have also been bored and pumping plants have been installed over them. The tract includes about 30,000 acres, and alfalfa, cereals, sugar beets, dairy and garden products, and fruits are produced successfully.

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Owner.		Classification.			
		Mineral content.	Chemical character.	Quality for boilers.	Quality for irrigation.
J. E. Meadows		High	$Ca\text{-}SO_4$	Bad	Good.
Do		...do	$Na\text{-}SO_4$	Very bad	Do.
		Very high	...do	...do	Poor.
E. P. McAdams		Moderate	$Ca\text{-}CO_3$	Fair	Good.
F. Blakeley		High	$Na\text{-}SO_4$	Bad	Do.
W. D. Sprague		Moderate	$Na\text{-}CO_3$	Fair	Fair.
Rhodes estate		...do	...do	Bad	Poor.
R. W. Dougherty		...do	...do	Very bad	Do.
M. A. Heinlen		High	$Na\text{-}SO_4$	Bad	Good.
Do	8	...do	$Na\text{-}CO_3$	Very bad	Poor.
C. C. Friend		...do	...do	...do	Do.
	5	Very high	$Na\text{-}SO_4$	...do	Do.
W. N. Stratton	9	High	$Na\text{-}CO_3$	...do	Do.
J. F. Poole	2	...do	$Na\text{-}SO_4$	...do	Do.
C. E. Mort	8	...do	$Na\text{-}CO_3$	...do	Do.
Mrs. M. Dutra		Low	$Ca\text{-}CO_3$	Good	Good.
William Hogle		Moderate	$Na\text{-}CO_3$	Fair	Fair.
D. Ross		...do	...do	Bad	Do.
Ernest Howe		...do	...do	Fair	Do.
A. P. Reiding		...do	...do	...do	Do.
W. S. Burr		...do	...do	Bad	Do.
Mrs. E. M. Killmer	6	High	...do	Very bad	Poor.
Dallas school district	3	...do	...do	...do	Do.
J. Martella		Moderate	...do	Fair	Fair.
Do		...do	Na-Cl	...do	Do.
	4	Very high	$Na\text{-}SO_4$	Very bad	Poor.
W. H. Thayer		Moderate	$Ca\text{-}CO_3$	Fair	Good.
Pacific Sugar Corporation		...do	$Na\text{-}CO_3$	...do	Fair.
City of Corcoran		...do	...do	Good	Do.
D. W. Lewis		...do	...do	Fair	Do.
L. P. Denny	1	Very high	...do	Very bad	Bad.
Jess & Gates	6	...do	$Na\text{-}SO_4$	...do	Poor.
Do		Moderate	$Na\text{-}CO_3$	Fair	Fair.

a C...
b Co...
c Co...

f Color, 40 parts.
g Color, 140 parts.

Owner.	Date.	Classification.			Analyst.
		...mical ...racter.	Quality for boilers.	Quality for irrigation.	
W. D. Sprague	Nov. 9, 1910	CO_3...	Fair	Fair	F. M. Eaton.
Rhodes estate	...do...	...o...	Bad	Poor	Do.
Southern Pacific Co...	June 25, 189...	Cl...	Fair	Fair	Southern Pacific Co.
Santa Fe Ry. Co	Oct. 1, 1902	...o...	...do	...do	Kennicott Water Softener Co.
Pacific Coast Oil Co...	...	...o...	Good	Good	Pacific Coast Oil Co.
Santa Fe Ry. Co	Oct. 1, 1902	CO_3...	Very bad	Poor	Kennicott Water Softener Co.
L. P. Denny	Nov. 23, 1910	...o...	...do	Bad	F. M. Eaton.
Jess & Gates	...do...	...o...	Fair	Fair	Do.

; depth unknown.

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QUALITY OF WATER.

The quality of the water around Tulare Lake has been discussed in detail in pages 104–109. Along the northern and eastern borders of the county dependence is placed almost exclusively in artesian wells 1,000 to 2,000 feet deep for irrigation supplies. These wells yield fair water. Close to the lake and within its borders wells 20 to 300 or 400 feet deep yield very poor water, but the quality of water between those depths grows better in proportion to distance from the center of the lake.

Means's tests reported by Lippincott[1] indicate that the waters near the surface immediately east and southeast of Hanford are poor in quality; the areas around the 40-foot well in sec. 1, T. 19 S., R. 21 E., and the 42-foot well in sec. 2, T. 18 S., R. 23 E., may form part of the same territory.

Wells 1,200 to 1,800 feet deep along the eastern border of the county yield water excellent for all uses.

Three sulphate waters west of the lake are acceptable in irrigation; that from the 285-foot well in sec. 24, T. 21 S., R. 18 E., is being applied to vines, garden truck, and small fruit trees. The quality of water likely to be struck by wells south and southwest of the lake is problematical for that region includes the marshy overflow lands across which the discharge of Kern River has passed, and as the silts there have probably been derived from both east-side and west-side encroachments it can not be assumed that the waters from them would be of the west-side type. It seems probable, however, that supplies similar to those in T. 22 S., R. 22 E., would be found in T. 23 S., R. 22 E., and that artesian waters in T. 22 S., R. 19 E., and T. 23 S., R. 20 E., would be similar to that from the 225-foot well in T. 22 S., R. 19 E.

[1] Lippincott, J. B., Storage of water on Kings River, California: U. S. Geol. Survey Water-Supply Paper 58, pp. 56–79, 1902.

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WELL RECORDS.

The details of depth, cost, equipment, and use of such wells as the Survey has examined have been assembled in the accompanying table.

TABLE 58.—*Records of wells in Kings County.*

Owner.	Location. Section.	Township south.	Range east.	Year completed.	Type and diameter of well.	Depth of well.	Depth to water level.	Temperature of water.	Method of lift.	Use of water.a	Yield.	Cost of well.	Cost of machinery.
						Feet.	*Feet.*	°*F.*			*Miner's inches.*		
Sacramento Bank	3	17	22	1895	Bored, 5 inches	107	12	.....	Hand	D	.....	.....	$4.00
E. Rae	4	17	22	1888	do	50	15	.....	do	D, S	.....	$37	5.00
S. Sweet	1	17	22	1889	do	34	9	66	do	D	.....	17	.....
E. Jacobs	25	17	22	1884	do	35	8	.....	do	D	.....	.....	3.50
David Burris	25	17	22	1885	Bored, 8 inches	60	9	.....	Wind	D, S	.....	45	6.00
Do	27	17	22	1886	Bored, 5 inches	40	12	.....	Wind, hand	D	.....	.....	.....
Mr. Van Dorset	22	17	22	1900	do	33	9	.....	Hand	D, S	.....	33	5.00
T. J. Alcorn	29	17	21	1900	do	44	8	.....	do	D	.....	60	4.00
C. W. Clark	25	17	21	1900	do	42	11	.....	do	D, S	.....	.....	.....
C. J. McCullah	36	17	21	1885	do	60	11	.....	do	D, S	.....	14	5.00
Boston Raisin Co	35	17	21	1890	do	52	7	.....	do	S	.....	36	3.50
A. J. Cortner	3	18	21	1896	do	52	10	.....	do	D, S	.....	26	3.50
Mr. Jenkins	1	18	21	1891	do	38	12	.....	do	D	.....	28	3.00
Cosmos Land & Water Co	4	18	22	.....	do	30	8	.....	do	D, S	.....	.....	3.00
Montgomery Bros	33	17	22	1874	Bored, 6 inches	65	8	.....	do	D	.....	65	6.00
David Burris	34	17	22	1900	Bored, 5 inches	56	13	.....	do	D	.....	28	3.50
S. A. Thompson	12	18	22	1900	do	58	8	.....	do	D, S	.....	37	6.00
J. R. High	10	18	22	1889	do	66	8	.....		D	.....	.....	.....
E. Jacobs	20	18	22	1897	do	25	6	.....	Hand	D	.....	13	.....
L. N. Gregory	17	18	22	.....	do	.....	11	.....	do	D, S	.....	.....	3.00
M. Bassett	13	18	21	1888	do	82	7	.....	do	D	.....	41	4.00
S. S. Serderberg	14	18	21	1898	do	44	10	.....	do	D, S	.....	22	4.00
Mrs. M. A. Haws	11	18	22	1886	do	54	8	.....	do	D, S	.....	39	3.50
J. W. Lane	9	18	21	1891	do	50	8	.....		D	.....	.....	.....
C. Lathan	22	18	21	.....	do	61	9	.....	Wind	D	.....	31	30.00
Mr. Page	18	18	21	1890	do	40	6	.....	do	D, S	.....	20	65.00
Mike Dutra	24	18	20	1900	do	24	8	.....	Hand	D, S	.....	.....	4.00
Wm. Hogle	22	18	21	1889	do	50	9	.....	do	D	.....	.....	4.00
J. O. Hickman	23	18	21	1897	Bored, 2 inches	100	8	.....	do	D, S	.....	50	4.50
J. C. Rice	25	18	21	1900	Bored, 5 inches	24	7	.....	do	D, S	.....	18	4.00
	18	18	22	1888	do	54	6	.....	Wind	D, S	.....	49	38.00

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Wetmore Bros.	29	18	22	1885	Bored, 7 inches	35	8		Wind, hand	D, S		27		
H. Marshall	17	18	22	1900	Bored, 5 inches	92	7		Hand	D, S				
E. W. Morgan	15	18	22	1888	do	60	9		do	D, S				5.00
E. Y. Bock	24	18	22	1878	Bored, 4 inches	70	12		do	D, S				
J. McCabe	21	18	23	1891	Bored, 5 inches	37	11	70	Wind	D, S		20		200.00
Alexander Taylor	22	18	22	1894	do	40	7		Hand	D, S		20		4.00
F. G. Ferreiro	22	18	22		do	35	6		do	D				4.00
Perry C. Phillips	25	18	22	1900	do	138	12		do	D				
Do	36	18	22		do		16		do	D				4.00
Joe Rogers	28	18	22		do		11		do	D				3.00
C. Waldorf	5	19	22		Bored, 4 inches		8		do	D, S				6.00
Frank Griffith	29	18	22	1894	Bored, 5 inches	38	12		do	D		27		
Mr. Dunner	31	18	22	1888	do	28	10		do	D, S		14		3.00
J. E. Rawlins	1	19	21	1882	Bored, 6 inches	42	10.5		Wind	D, S		42		150.00
A. L. Cressy	35	18	21	1884	Bored	25	10		do	D, S		25		50.00
P. C. Eccles	35	18	21	1891	Bored, 4 inches	40	10		do	D, S				
W. V. Walker	34	18	21	1890	Bored, 5 inches	35	10		Hand	D, S				3.00
Maria Reynolds	33	18	21	1885	do	36	12		do	D				6.00
Ben Scribner	4	19	21		do	70	10		do	D				4.00
W. W. Robinson	31	18	21	1888	Bored, 6 inches	42	10		do	D		21		3.50
Mrs. M. Camp	30	18	21	1880	Bored, 5 inches	32	10		Wind	D		32		53.00
W. J. Weir	36	18	20	1890	do	40	10		Hand	D				
Mrs. H. Bryant	36	18	20	1880	do	50	12		do	D		50		4.00
Mrs. Hunkey	34	18	20		do		8		do	D, S				4.00
R. M. Coon	4	19	20	1887	Bored, 8 inches	52	8		Wind	D				
Lemoore Electric Light & Waterworks Co.[b]	3	19	20	1902	Bored, 7 inches	180	0		Steam, artesian	D	11	300		
O. D. Brown	1	19	20	1883	Bored, 5 inches	40	4		Hand	D, S				3.00
C. Manter	8	19	21	1879		50	8		do	D, S				3.00
Chas. Feahill	9	19	21	1890	Bored, 5 inches	48	8		do	D		23		3.50
F. E. Wood	3	19	21	1890	do	50	8		do	D, S				
Mrs. M. Andrews	20	19	21	1882	do	60	10		do	D				4.00
John Wynrck	2	19	21	1884	Bored, 7 inches	608	0		Artesian	D, S	2	1,333		
Philips estate	7	19	22	1895	Bored, 5 inches	40	10		Hand	D, S				6.00
M. Braverman	9	19	22		do		9		do	D, S				
Harry Peacock	3	19	22	1873	do	75	9		Wind, hand	D				
R. Abbott	3	19	22	1899	Bored, 4 inches	100	9		Hand	D, S		50		3.00
J. H. Murray	12	19	22	1892	Bored, 5 inches	43	14		do	D, S		40		3.25
P. Sweeney	14	19	22	1878	do	40	8		do	D, S		40		2.25
G. L. Fletcher	15	19	22	1889	do	56	10		do	D, S		56		
Mrs. M. J. Covert	22	19	22	1878	do	40	14		Hand, wind	D, S				
Susan Hill	20	19	22	1899	do	30	10		Wind	S				35.00
F. L. Sanborn	18	19	23	1903	do	46	12	66	do	S		25		
W. A. Sanborn	17	19	23	1875	Bored, 6 inches	40	14	69	Hand	D, S		20		4.00
F. L. Sanborn	25	19	22	1892	Bored, 7 inches	+32	12	66	Wind	S				
Robert Dougherty	23	19	22		Bored, 5 inches	30	14		Hand	D, S				
S. L. Worley	28	19	22	1880	do	30	13		do	D, S				3.50
S. A. Brewer	20	19	22	1891	do	54	12		do	D, S		30		2.50
California Savings & Loan Association	25	19	21	1880	Bored, 6 inches	55	9		do	D		55		7
C. H. Watson	19	19	22	1893	Bored, 5 inches	45	8		do	D, S				
R. S. Walt	13	19	21	1878	Bored, 6 inches	40	10		do	D				

[a] D, domestic; S, stock; I, Irrigation; B, boilers; N, not used.

[b] Two wells.

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TABLE 58.—*Records of wells in Kings County*—Continued.

Owner.	Location. Section.	Township south.	Range east.	Year completed.	Type and diameter of well.	Depth of well.	Depth to water level.	Temperature of water.	Method of lift.	Use of water.	Yield.	Cost of well.	Cost of machinery.
						Feet.	*Feet.*	°*F.*			*Miner's inches.*		
Fred Ward	26	19	21	.....	Bored, 5 inches	.....	9	.....	Steam	D	.....	.....	$130.00
John Sigler	26	19	21	1892	....do	65	12	.....	Wind	D, S	.....	.....	.....
J. R. Mullinix	14	19	21	1880	Bored, 6 inches	40	12	.....	Hand	D	.....	$41	4.00
Martin Roberts	22	19	21	1882	Bored, 5 inches	25	12	.....	....do	D	.....	.....	3.00
J. L. Walker	8	19	21	1897	....do	66	9	.....	....do	D, S	.....	33	4.00
L. R. Love	20	19	21	1890	....do	.....	12	.....	.....	D, S	.....	.....	.....
Geo. W. Houston	21	19	21	1890	....do	34	12	.....	Hand	D, S	.....	.....	4.00
B. R. Nidiffer	19	19	21	1875	....do	37	10	.....	....do	D, S	.....	.....	3.00
G. E. Shore	18	19	21	1889	Bored, 7 inches	40	10	.....	Wind, hand	D, S	.....	.....	.....
J. F. Florey	13	19	20	1885	Bored, 5 inches	40	8	.....	....do	D	.....	.....	.....
W. D. Runyon	12	19	20	1896	....do	122	7	.....	Hand	D, S	.....	61	3.50
E. W. Clithero	14	19	20	1890	....do	60	6	.....	....do	D, S	.....	.....	6.00
Mrs. E. Cory	14	19	20	1882	Bored, 6 inches	33	8	.....	....do	D	.....	17	3.25
R. W. Dougherty	15	19	20	1892	Bored, 5 inches	139	3.5	.....	....do	D, S	.....	108	4.00
John Hunlen	16	19	20	.....	Bored, 7 inches	+100	0	.....	Artesian	D	Small.	.....	.....
M. A. Heinlen	8	19	21	1897	Bored, 4 inches	135	0	.....	....do	D, S	.....	135	.....
Do	20	19	20	1901	Bored, 2 inches	265	0	76	....do	S	Small.	.....	.....
Bates & Miller	19	19	20	1902	....do	335	0	77	....do	S	Small.	.....	.....
M. A. Heinlen	21	19	20	1880	Bored, 7 inches	400	0	77	....do	S	Small.	.....	.....
M. Hinniel	21	19	20	.....	Bored, 6 inches	36	6	.....	Hand	D	.....	20	.....
M. A. Heinlen	28	19	20	1902	Bored, 5 inches	34	7	.....	....do	D, S	.....	17	.....
C. C. Frand	29	19	20	1905	Dug, 2 feet	16	5	.....	....do	D	.....	.....	.....
Do	29	19	20	.....	Bored, 6 inches	590	2	.....	....do	S	.....	.....	.....
E. P. McAdams	25	19	19	1897	Bored, 4 inches	38	6	66	....do	D, S	.....	20	.....
Bates & Miller	6	20	20	1903	Bored, 2 inches	350	0	.....	Artesian	S	Small.	.....	.....
M. A. Heinlen	5	20	20	1895	....do	398	0	77	....do	S	Small.	400	.....
Harris & Hereford	33	19	20	1904	Bored, 5 inches	34	7	66	Hand	D, S	.....	.....	.....
Jacobs estate	27	19	20	.....	Bored, 9 inches	.....	0	77	Artesian	S	3	.....	.....
L. Hereford	22	19	20	1885	Bored, 12 inches	36	6	.....	Hand	D	.....	.....	.....
J. Childres	26	19	20	.....	Bored, 6 inches	30	5	.....	....do	D	.....	15	.....
S. T. Whiteside	26	19	20	.....	Bored, 5 inches	46	6	66	....do	.....	.....	26	.....
W. Blevins	26	19	20	1892	Bored, 6 inches	40	10	.....	....do	D, S	.....	20	3.00
E. Jacobs	2	20	20	.....	Bored, 9 inches	.....	0	.....	Artesian	D, S	Small.	.....	.....
E. G. Sellers	36	19	20	1895	Bored, 5 inches	52	12	.....	Hand	D	.....	.....	3.50
Marriott & Mathus	30	19	21	1898	....do	104	12	.....	....do	D, S	.....	54	3.50
M. F. Mines	4	20	21	1891	....do	83	14	.....	....do	D, S	.....	.....	3.00
C. Paddock	4	20	21	.....	....do	35	13	.....	....do	D, S	.....	.....	3.50
W. Burr	10	20	21	.....	Bored, 7 inches	.....	13	.....	....do	D	.....	.....	4.00

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W. S. Burr	2	20	21	1900	Bored, 5 inches	44	16		Wind	D, S		22	31
John Bowers	36	19	21	1894	Bored, 9 inches	800	0		Artesian	D, S		1,600	
A. P. Redding	36	19	21	1889	Bored, 10 inches	753	0		do	I, D	38	2,600	
Mrs. J. Hide	12	20	21		Bored		15		Hand	D, S			5.00
Geo. Clute	31	19	22	1885	Bored, 10 inches	900	0		Artesian	I, D, S		1,900	
A. & J. Toomey	32	19	22		Bored, 6 inches		0		do	S			
Lakeside Creamery Co	33	19	22	1890	Bored, 5 inches	60	15		Hand	D		45	12.00
Mrs. J. T. Hereford	34	19	22	1875	Bored, 6 inches	40	11		do	D		40	6.00
E. McCarthy	3	20	22		Bored, 5 inches	64	14		do	D, S		64	2.75
J. McCann	2	20	22	1904	do	32	10	67	do	D		16	
Mr. Hunter	13	20	22	1890	Bored, 9 inches	+900	0	77	Artesian	I, S	36		
W. H. Heidebrand	10	20	22	1880	Bored, 5 inches	34	16		Wind	D, S		34	114.0
P. McCarthy	8	20	22	1886	Bored, 9 inches	600	0		Artesian	I, D, S		1,500	
F. E. Howe	8	20	22	1891	Bored, 8 inches	750	0		do	I, D, S		1,250	
J. McCann	15	20	22	1905	Bored, 5 inches	38	8	66	Hand	D			
Do	21	20	22		do	35	8		do	D			
Mrs. E. M. Killmer	25	20	21		Hydraulic, 2 inches	95	12	67	Wind	D, S		50	
Henry C. Smith	26	20	21	1904	Bored, 2 inches	400	0		Artesian	S		2	400
J. Boyle	36	20	21		Bored, 8 inches	700	0	73	do	D, S		33	
Dallas school district	36	20	21	1905	Bored, 2 inches	400	0	73	do	D		1	
Mr. Martelas	1	21	21		Bored, 11 inches	1,100	0	76	do	D, S		34	
Jacobs estate	7	20	21		Bored, 9 inches		0	77	do	S		9	
Do	13	20	20		do		0		do	S		26	
Do	11	20	20	1883	do		0	77	do	S		9	
Do	2	20	20		do		0	77	do	S		9	
Pacific Coast Oil Co	10	20	20	1904	Bored, 10 inches	820	0	77	do	B		30	
Bates & Miller	16	20	20	1890	Bored, 7 inches	775	0		do	D, S		7	
Jacobs estate	23	20	20		Bored, 9 inches		0	77	do	S		3	
Do	27	20	20		do		0		do	S		46	
Bates & Miller	33	20	20		Bored, 2 inches	360	0		do	N			
Do	32	20	20	1903	do	325	0	76	do	S	Small.		
Do	30	20	20	1903	do	350	0	76	do	S	Small.		
Do	31	20	20	1900	do	260	0	76	do	S	Small.	260	
Edgar & Combs	1	21	19	1905	do		0	76	do	S	Small.		
F. Blakeley	11	21	19	1895	do	217	0	76	do	S	Small.		
N. L. Palmer	22	21	18	1892	Bored, 8 inches	210	40		Wind	N			
F. Blakely	5	22	19	1890	Bored, 2 inches	225	0	76	Artesian	S	Small.		
Do	3	22	19		do	236	0		do	S	Small.		
L. D. Combs	12	21	19		do	250?	0	76	do	S	Small.		
G. A. Smith	8	21	20		do	225	0	76	do	S	Small.		
M. Lovelace	5	21	20	1903	do	250	0		do	S	Small.		
Do	5	21	20	1901	do	300	0	76	do	D, S	Small.		
Do	4	21	20	1903	do	250	0	74	do	S	Small.		
Do	4	21	20	1904	do	240	0	75	do	S	Small.		
R. Mills	15	21	20	1904	do	350			Not raised	N			
Sam Richardson	16	21	21		do	200	0		Artesian	S			
Do	22	21	21		Bored, 3 inches	90	0	66	do	S, D	Small.		
J. Martella	1	21	21	1905	Bored, 10 inches	1,600	0	78	do	I, S	36		
Mrs. McDonald	12	21	21	1905	Bored, 8 inches	1,250	0		do	I, D, S			
R. G. Hunter	6	21	22	1901	Bored, 6 inches	450	0	74	do	S		500	
	19	21	22		Hydraulic, 2 inches		0	72	do	S	Small.		
	20	21	22		do		0	70	do	D, S	Small.		

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TABLE 58.—*Records of wells in Kings County*—Continued.

Owner.	Location. Section.	Township south.	Range east.	Year completed.	Type and diameter of well.	Depth of well.	Depth to water level.	Temperature of water.	Method of lift.	Use of water.	Yield.	Cost of well.	Cost of machinery.
						Feet.	*Feet.*	°*F.*			*Miner's inches.*		
F. Ganahl	30	21	22	.....	Hydraulic, 2 inches	350	0	70	Artesian	D, S	3	.....	.....
D. W. Lewis	21	21	22	1905	Bored, 6 inches	1,225	0	74	do	I	22	.....	.....
Do	21	21	22	1905	do	1,200	0	74	do	I	33	.....	.....
Do	21	21	22	1905	do	1,247	0	72	do	I	43	$1,550	.....
Do	21	21	22	1905	do	1,106	0	72	do	I	.....	.....	.....
Security Land & Loan Co	14	21	22	.....	Bored, 8 inches	.....	0	74	do	I	8	.....	.....
Do	14	21	22	.....	do	.....	0	74	do	I, D, S	8	.....	.....
Do	14	21	22	1905	Bored, 12 inches	928	0	71	do	I	30	3,000	.....
Do	24	21	22	1891?	Bored, 7 inches	.....	0	71	do	I	20	.....	.....
A. Y. Thayer	13	21	22	1905	Bored, 13 inches	60	10.5?	.....	Gas	I	[a] 33	50	$800.00
W. H. Thayer	13	21	22	.....	Bored, 5 inches	40	10	.....	Hand	N	.....	20	4.00
Dr. Dixon	4	22	22	.....	Bored, 2 inches	150?	0	66	Artesian	S	Small.	.....	.....
N. Hausen	10	22	22	1905	Hydraulic, 2 inches	360	0	68	do	D, S	.....	180	.....
Mrs. Duncan	10	22	22	1904	Bored, 6 inches	350	0	71	do	D, S	.....	.....	.....
L. P. Denney	15	22	22	1901	Bored, 8 inches	950	0	72	do	I, D, S	24	2,400	.....
Do	14	22	22	1904	Hydraulic, 2 inches	250	0	72	do	S	Small.	300	.....
C. Lamberson	12	22	22	.....	Bored, 8 inches	.....	0	76	do	D	[a] 25	.....	.....
	13	22	22	.....	do	.....	0	75	do	I, S	17	.....	.....
	13	22	22	.....	Hydraulic, 4 inches	.....	0	68	do	I, S	2	.....	.....
	13	22	22	.....	Bored, 6 inches	.....	0	78	do	I, S	44	.....	.....
O. P. Quimby	24	22	22	.....	Bored, 12 inches	1,200	0	78	do	I, D, S	13	3,000	.....
Robert Boot	25	22	22	1905	Bored, 6 inches	1,540	0	85	do	I, D, S	61	4,000	.....
Do	25	22	22	1904	Bored, 2 inches	308	0	71	do	S	Small.	.....	.....
	20	22	22	.....	Bored, 12 to 10 inches.	.....	0	70	do	N	Small.	.....	.....
R. D. Hunter	30	22	22	1905	Hydraulic, 2 inches	120	20?	70	Hand	S	.....	70	5.00
Southern California Savings Bank	4	23	22	.....	do	400	0	.....	Ceased flowing	S	.....	.....	.....
J. N. Sherwin	7	23	21	1904	do	200	2	.....	Horse	S	.....	200	100.00
F. Blakeley	17	22	20	.....	Bored, 2 inches	262	0	.....	Artesian	S	Small.	.....	.....
Do	19	22	20	.....	do	200+	0	.....	do	S	Small.	.....	.....
Miller & Lux	28	24	22	.....	Bored, 8 inches	.....	0	77	do	I, D, S	23	.....	.....
Pacific Coast Oil Co	14	21	22	.....	Bored, 9½ to 8 inches	850	0	.....	do	B	13	.....	.....
Do	10	20	20	1904	Bored, 10 to 8 inches.	1,000	0	.....	do	B	3	.....	.....

[a] Yield estimated or statement of owner taken.

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KERN COUNTY.

GENERAL CONDITIONS.

Kern County, which includes the extreme southern end of the San Joaquin Valley, receives its principal water supply, both surface and underground, from Kern River, which flows out upon the valley floor just above Bakersfield. Minor amounts, chiefly as winter flood waters, are contributed by Poso Creek and the streams that enter the valley from the south and west. The supply in excess of that used by the canal systems flows into Buena Vista Reservoir, where it is stored for the irrigation of the Miller & Lux lands along the trough of the valley to the north. During seasons of particularly heavy stream flow, a portion of the water escapes northward along either the main channel or Goose Slough channel toward Tulare Lake. This county has the least precipitation of all those in San Joaquin Valley, the average for a long period at Bakersfield being 4.81 inches,[1] and consequently the direct supply of surface water is markedly small.

In the course of its distribution over the delta lands through the canals in irrigation, and by flow through the natural distributaries, a definite portion of the water sinks and so maintains a condition of saturation of the sands and gravels that have been deposited in the course of the growth of the delta. These saturating waters, like the surface waters, move in the direction of the slope of the delta, but at a much slower rate. They circulate more freely through the coarser beds of the delta deposits, and as they pass beneath the finer beds that are more numerous in those parts of an alluvial fan that are most distant from its head they accumulate pressure. Therefore when the confining beds above them are pierced by a well they rise, and if the pressure is sufficient they flow over the surface. These are the flowing artesian wells of the beds of Kern and Buena Vista lakes and the region extending some miles north of them, and of the main San Joaquin Valley artesian basin, beginning in the neighborhood of Buttonwillow and extending thence northward down San Joaquin Valley to the delta of San Joaquin and Sacramento rivers. It may connect with the Buena Vista artesian area, although there is no evidence available now to determine this point.

FLOWING WELLS.

In 1905 there were 112 flowing wells in the county that were examined, and there were doubtless a few more that were not seen. The yield of these was in the neighborhood of 70 or 75 second-feet. About one-third of the wells were used for irrigation, the remainder being

[1] Cone, V. M., Irrigation in the San Joaquin Valley, California: U. S. Dept. Agr. Off. Exper. Sta. Bull. 239, p. 11, 1911.

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used for stock or domestic purposes or allowed to waste. The areas in which they occur are indicated by the outlines of the artesian basins, as shown on Pl. I (in pocket).

Generally speaking, the artesian pressures have not been seriously affected by the developments that have taken place to date, although there are some wells, as in the Semitropic district, whose flow has decreased markedly as a result of the boring of big wells near by, but on lower ground and therefore in more favorable situations. Artesian wells usually deteriorate with age, as a result of any one of several causes, as slow filling with sand, clogging by gelatinous growths of microscopic organisms, and deterioration of the casing.

The State Engineering Department of California measured the yield of certain flowing wells in the Kern delta in 1885, and some of these were remeasured in 1905. The remeasured wells show decreases in yield varying from 50 to 100 per cent, but in only one of the wells available for comparison has there been complete cessation of flow. Decrease in yield of individual wells as development progresses is so usual a phenomenon that no community can safely plan its future on the assumption that a cheap supply of this type will remain constant, even in such large basins as those of the San Joaquin. But flowing water should be available for years from those wells whose initial yield is sufficiently large to be of value. Later, when the communities are more thickly settled and the wells are so closely grouped that flow and yield are materially decreased, industrial conditions may have so changed that pumps can profitably be installed to augment the supply. The cost of such pumped waters will usually be particularly low, because of the slight lift required to bring them to the surface.

PUMPING PLANTS.

In 1906 there were more than 100 pumping plants in Kern County developing underground water for various purposes. Of these about 40 were gas plants, 25 were steam plants, and the rest were electric. Nearly all of the steam plants have been abandoned or replaced with plants using gas engines or electric motors. The developed waters are used for irrigation, for city supplies, for engine waters, and as supplies for steam plants, as at the pumping stations of the Pacific Coast Oil Co.

In the district about Bakersfield 50 pumping plants are in use to develop irrigation water. Half of these are electrically operated and belong to the Kern County Land Co. Each of these plants is equipped with 30 or 40 horsepower motors directly connected with No. 8, 10, or 12 centrifugal pumps. Each pump is connected with from one to four 13-inch wells, the number being determined by the yield of each well. From the data collected on these wells the fol-

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lowing cost averages were computed on the basis of the quoted charge of 15 cents per horsepower per 24 hours for the electric power used.

TABLE 59.—*Data concerning pumping plants in Kern County.*

Average depth to the water from the surface, in feet	10
Average suction 20 feet. Average total lift, in feet	30
Total yield of 25 plants, in second-feet	100.34
Total horsepower consumed	860
Total cost per day for current to develop 100.34 second feet, 860 H. P., at 15 cents	$129.00
Cost per second-foot for 24 hours	$1.29
Cost per acre-foot of water developed	$0.65

The company estimates that other items bring the total cost of operation and maintenance to $1.70 per second-foot for 24 hours or 85 cents per acre-foot. Taxes, interest, and depreciation amount to about 15 per cent on the investment, and as the plants are operated about 100 days a year these items increase the total cost of developing ground water to $3 per second-foot for 24 hours or $1.50 per acre-foot.

The standard of water costs in this district is set by the price of gravity water from the Kern—75 cents per second-foot for 24 hours, or about 38 cents per acre-foot, where distribution is affected by sales.

The pumped water therefore, even under the excellent system of the Kern County Land Co., costs about four times as much as the gravity water, and its cost will increase as it is developed from deeper strata with higher lifts. It seems to be quite generally believed locally that water at these prices can not be used profitably.

This may be true with the wasteful methods employed, the excessive amounts of water often applied, the class of crops produced, and the general lack of intensive cultivation; but it has been clearly proved in other communities and by individual experiences in the Bakersfield region itself that with more diversified or better selected crops, smaller individual holdings, and more intensive methods of farming, good profits may be made from the alkali-free lands of the delta and plains by the careful use of water at these or at even higher prices. It is safe to predict that the most important future developments in Kern County will result from the application of these principles.

Under any conditions that are likely to obtain in the near future it is not to be expected that ground waters at greater depths than 25 or 30 feet below the surface as an extreme will be usable for irrigation purposes. Water at this or less depths exists, of course, throughout the artesian areas along the lowest parts of the valley. It is to be found also throughout the greater part of Kern delta and in the lower parts of Poso Creek delta from a point about halfway between Famoso and Wasco westward. Near the foothills on each side of the

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valley the ground water is not accessible except under unusual conditions, as in the flood plains of the larger rivers, or in areas where particularly valuable products, such as citrus fruits, will justify the expense of pumping to exceptional heights. In the intermediate areas between the deltas of the streams that supply the ground water it is also apt to be too deep to be accessible. This condition is illustrated in the area between Kern and Poso Creek deltas, east of Shafter station, on the Santa Fe Railway, and in the region between Delano and the foothills just south of the Tulare County line.

Near the northern edge of the county the main artesian belt of the valley, whose southern end is in the vicinity of Buttonwillow, expands to a width of 26 or 27 miles measured along the county line. Much of this central portion of the valley along the north edge of Kern County is in large holdings and is therefore but thinly settled, but developments are ample to prove the artesian conditions and to permit outlining the artesian belt with a fair degree of accuracy. The outlines as determined are shown on the map (Pl. I, in pocket), which also shows by means of hydrographic contours the depth to the ground-water level outside the artesian limits.

Although little direct evidence bearing upon this point exists, there can be no doubt that beneath the broad steeply sloping west-side plains of Kern County the ground water a few miles back from the trough of the valley is too deep to be accessible, because the water table has but little slope, the depth to it at any point being approximately equal to the elevation of that point above the trough of the valley.

QUALITY OF WATER.

The information regarding the quality of the ground waters of Kern County is more or less local, and therefore generalizations can not be made with such definiteness as in other parts of the valley. Water from wells of different depths around Delano, Famoso, and Oil Center was tested, and the basin of Kern Lake was explored. A line of assays was made from Famoso to Semitropic, and deep and shallow waters were examined as far west as Buttonwillow and T. 25 S., R. 23 E.

The chemical composition of waters in Kern County is somewhat different from that of supplies farther north, especially in respect to the distribution of sulphate. Five wells 43 to 220 feet deep at Delano yield waters good for irrigation and fair to poor for boiler use; all contain appreciable amounts of sulphate, but they are not nearly so strongly mineralized as the water of an 18-foot well, which carries 1,600 parts of total solids. Three wells east of Delano in T. 25 S., R. 26 E., 80 to 180 feet deep, yield sodium carbonate water low enough in mineral content to be good for irrigation. Water

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from two wells 108 and 118 feet deep at Delano is being successfully used in irrigating orange trees.

Flowing wells 300 to 995 feet deep at Pond pumping station and west of there in T. 25 S., R. 24 E., yield sodium carbonate waters low in mineral content like those along the western border of Tulare County, and these waters have been used to irrigate alfalfa, grain, garden truck, and trees. The only shallow well that was tested gives a sodium sulphate water of poorer quality. The supply from a 700-foot well at Pond pumping station is used in boilers without treatment except preheating, and the assay shows that the water is low in all harmful constituents.

Wells 50 to 175 feet deep at Famoso yield calcium carbonate water, acceptable for irrigation and somewhat lower in mineral content than the average water of the east-side type farther north. Wells of similar depth west of Famoso yield inferior sodium carbonate water higher in sulphate. Wells 172 to 326 feet deep around Semitropic still farther west have supplies similar to those at Pond, and their waters have been similarly used. Water from the 480-foot well in sec. 8, T. 27 S., R. 23 E., curiously enough, is much higher in chlorine than that from the other wells. As the water of a 1,150-foot well in the same section has not been used for a long time and stands below the top of the casing the complete test of its water is not reported, but it shows the presence of 235 parts per million of chlorine. Water from the artesian well of S. B. Anderson, west of Semitropic, the depth of which is not reported, contains more than 700 parts of chlorine, according to an examination made in the State laboratories. All these wells probably lie in the eastern edge of a highly mineralized area, for deep waters east of this locality are low in chlorine.

The water that is pumped with the oil from wells in Kern River field contains little sulphate or chloride, but it is very hard. A battery of wells about 400 feet deep in sec. 5, T. 29 S., R. 28 E., and a 200-foot well in sec. 7, T. 29 S., R. 28 E., furnish boiler and drinking water moderate in mineral content and much better than that from deeper wells. No pretreatment is necessary for these supplies, and only a small amount of eggshell scale has to be removed from the boilers every two weeks.

Shallow waters as far south of Bakersfield as Kern Lake basin are fair for use in boilers and good for irrigation, as they are calcium carbonate waters of moderate mineral content. Their situation in a well-cultivated region supplied with surface water partly explains their excellent quality. The deeper waters in the lake basin farther south are of good quality, but they increase in sulphate southward, and those close to the foothills are bad. These changes are graphi-

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cally represented in section D′ E′, figure 4, and they are more fully discussed on pages 109–110.

The poor quality of the ground waters in an alkali belt immediately southeast of Kern is proved by the tests of supplies in the eastern part of T. 30 S., R. 28 E. Three waters from wells 60, 140, and 240 feet deep south of this area are better.

Four flowing wells northeast of Buttonwillow, 444 to 850 feet deep, yield similar supplies. As they are sodium carbonate waters of low mineral content, similar to those at Semitropic and Pond, it is reasonable to conclude that flowing wells east of range 23 between Buttonwillow and Kings River will yield water good or fair for irrigation and for boiler use. A shallow well in sec. 31, T. 28 S., R. 24 E., gives water of the same nature. The low, broad, but well-defined ridge that lies between the artesian area in T. 28 S., R. 24 E., and that in T. 29 S., R. 23 E., may separate the two flowing-well basins. The fact that the three artesian supplies in the latter township are sodium chloride waters of poorer quality than those northward is significant but not conclusive, as conditions here may be analogous to those at Semitropic, where no such ridge exists. Two shallow wells at Buttonwillow yield hard water good for irrigation but poorer than that in T. 28 S., R. 24 E., while the 101-foot well at Buttonwillow depot yields still harder water.

Little information is available regarding the quality of the waters west of range 23, but the data given by Arnold and Johnson[1] regarding the springs and wells in the west-side hills establish their highly mineralized character. These supplies are probably similar in composition and concentration to the gypseous waters of western Fresno County.

[1] Arnold, Ralph, and Johnson, H. R., Preliminary report on McKittrick-Sunset oil region, Cal.: U. S. Geol. Survey Bull. 406, pp. 102–107, 1910.

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Owner.	Classification.				Analyst.
	al t.	Chemical character.	Quality for boilers.	Quality for irrigation.	
J. P. Irish	te..	Na-Cl	Bad	Fair	F. M. Eaton.
Southern Pacific Co		do	do	do	Southern Pacific Co.
Do	te..	$Ca-CO_3$	Fair	Good	Do.
Do		$Ca-SO_4$	do	do	Do.
Do		do	do	do	F. M. Eaton.
Do		$Ca-CO_3$	do	do	Southern Pacific Co.
Williams & Noyer		do	do	do	F. M. Eaton.
Southern Pacific Co		do	do	do	Southern Pacific Co.
Do		do	Good	do	Do.
Do	te..	$Ca-SO_4$	Poor	do	Do.
P. M. Wilkerson		$Ca-CO_3$	Fair	do	F. M. Eaton.
Kern County Land Co		$Na-CO_3$	Good	do	Do.
Southern Pacific Co		$Ca-CO_3$	Fair	do	Southern Pacific Co.
Petroleum Development Co.	gh.	Na-Cl	Very bad	Bad	F. M. Eaton.
Pacific Coast Oil Co		$Ca-CO_3$	Good	Good	Pacific Coast Oil Co.
E. A. Marriott	te..	do	Poor	do	F. M. Eaton.

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Such detailed facts about the various types of wells in Kern County as have been secured by the Geological Survey are assembled in the following table. The data were collected in large part by A. J. Fiske, jr.

TABLE 62.—*Records of wells in Kern County.*

Owner.	Location. Section.	Township south.	Range east.	Year completed.	Type and diameter of well.	Depth of well.	Depth to water level.	Temperature of water.	Method of lift.	Use of water.[a]	Yield.	Cost of well.	Cost of machinery.
						Feet.	*Feet.*	°*F.*			*Miner's inches.*		
Miller & Lux	11	25	21	.....	Bored, 8 inches	.....	0	78	Artesian	S	26	.....	.....
Fred Cox	20	25	22	1901	Bored, 14 inches	800	0	78	do	D, S, I	[b] 262	$3,000.00	.....
Miller & Lux	4	25	22	.....	Bored, 8 inches	250	0	74	do	D, S, I	11	.....	.....
Fred Cox	23	25	22	.....	Bored, 7 inches	.....	0	75	do	S	2	.....	.....
Miller & Lux	3	25	23	.....	Bored, 8 inches	.....	0	74	do	S	28	.....	.....
Mr. Haley	1	25	23	.....	do	.....	0	70	do	I	60	.....	.....
	12	25	23	.....	Bored, 10 inches	.....	0	70	do	N	75	.....	.....
	7	25	24	.....	Bored, 6 inches	.....	0	70	do	N	3	.....	.....
Mr. Dorsey	10	25	24	.....	Bored, 8 inches	.....	0	71	do	I, S	22	.....	.....
	2	25	24	.....	do	.....	0	71	do	N	68	.....	.....
C. H. Dorsey	4	25	25	1891	Bored, 7 inches	45	14	.....	Wind	I	.....	45.00	$100
W. B. Timmins	10	25	25	1901	Bored, 8 inches	80	18	.....	do	D, S, I	.....	1.00	52
B. Thomas	3	25	25	1902	Bored, 10 inches	132	29	.....	Gas	I	44	125.00	85
Do	3	25	25	.....	do	56	29	.....					
Teresa Panero	10	25	25	.....	Dug, 3 feet by 3 feet.	18	17	66	Wind	D, S	.....	25.00	50
Margereta Pulvan	15	25	25	.....	Bored, 6 inches	20	16?	.....	Hand	D	.....	20.00	5
C. Conteras	10	25	25	.....	Bored	25	19	68	do	D	.....	.....	.....
C. F. McHarvey	11	25	25	.....	Bored, 8 inches	90?	30?	.....	Wind	S	.....	.....	25
Mr. Mallery	1	25	25	1889	Bored, 6 inches	70	32	.....	Wind, horse	D	.....	51.00	200
J. L. Williams	6	25	26	1890	Bored, 8 inches	100	65	.....	Wind	D, S	.....	122.50	35
C. C. Albert	6	25	25	1898	Bored, 7 inches	80	65	61	do	D, S	.....	100.00	60
Virgil Starwalt	8	25	26	.....	do	.....	70?	.....	Not raised	N	.....	.....	.....
Victor Vieux	8	25	26	1902	do	80?	65?	.....	Wind	D	.....	.....	100
Angelo Pecci	10	25	26	.....	do	130?	115?	.....	do	N	.....	.....	115
J. D. Smith	10	25	26	1887	do	150?	125?	.....	do	N	.....	135.00	115
John Vanlone	10	25	26	1888	do	140?	125?	.....	do	D	.....	140.00	87
Reed estate	2	25	26	1889	do	148	132	.....	Horse	S	.....	.....	.....

[a] D, domestic; S, stock; I, irrigation; B, boilers; N, not used.

[b] Yield estimated or statement of owner taken.

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W. L. Smith	9	26	27	1890	Bored, 8 inches	400	270?		Horse	D, S		1,000.00	300
	20	26	26		....do	100+	96		Wind	N			100
	20	26	26		Bored, 6 inches	84	64?		....do	D		60.00	100
H. L. Taylor	29	26	26	1894	....do	120	80?		....do	D		600.00	
C. E. Kitchen	29	26	26		....do	125	95?		....do	D		94.00	100
Robertson school district	32	26	26	1902	Bored, 8 inches	144	90?		....do	D		144.00	100
H. E. Phillips	31	26	26		Bored, 7 inches	83	65		Horse	D		60.00	75
Kern County Land Co	24	26	25	1889	Bored, 8 inches	65	20?	67	Wind	D		65.00	70
G. L. Robertson	14	26	25		Bored, 6 inches	82	35?		....do	D		60.00	100
Mrs. Susan L. Beebe	26	26	25	1886	....do	93	35?		....do	D		69.00	100
Kern County Land Co	23	26	25	1903	Bored, 10 inches	89	23	69	Gas				
Do	22	26	25	1904	....do		12	64	....do	S			
Do	21	26	25		Bored, 6 inches	82	26	66	Wind	D			
Do	27	26	25	1903	Bored, 10 inches	80	26		Gas	S			
Do	29	26	25	1903	....do	75	20		....do	S			
Do	17	26	24		Bored, 8 inches	512	0	79	Artesian	S	31		
Do	19	26	24		Bored, 10 inches	480	0	78	....do	S	52		
R. B. Johnson	34	26	23	1886?	Bored, 8 inches	369	0	78	....do	S, I	56		
C. J. Clayton	32	26	23	1885	Bored, 10 inches	284	0	78	....do	S	119		
J. D. Wells	34	26	22	1885	Bored, 8 inches	320		76	Gas	I	89		900
T. W. Brown	34	26	22	1886	....do	470	0		Artesian	I	10		
Do	34	26	22	1901	....do	700	0		Gas; artesian	I	5	1,000.00	1,000
W. Y. Horner	2	27	22	1894	....do	599	5		Gas	I	133		[a] 1,175
Paige & Montgomery	6	27	23		....do	800	0	82	Gas; artesian	I	67		
Mr. Brown	5	27	23		....do		0	76	Artesian	I, S	8		
Mrs. O'Brien	9	27	23	1889	....do	360	0		....do	N	Small.		
Mrs. C. Davis	4	27	23	1884	....do	234	0	76	....do	N	[b] 10		
P. Irish	8	27	23	1895	....do	480	7		Gas	I	133		[a] 1,650
Do	8	27	23	1889	Bored, 9 inches	1,150	2		Not raised	N			
Harry Rambow	10	27	23	1888	Bored, 8 inches	423	0	76	Artesian	D, S, I	6		
Kern County Land Co	2	27	23		Bored, 7 inches		0	76	....do	S	[b] 35		
Do	12	27	23		Bored, 8 inches	533	0		....do	S			
Do	8	27	24		Bored, 10 inches	890	0		Not raised				
	10	27	24		....do		17		Wind, hand, gas	D, S			
Do	6	27	25	1903	....do	86	20	70	Gas				
J. McCombs	8	27	25		Bored, 7 inches	89	29	64	Wind	D			
Kern County Land Co	17	27	25	1903	Bored, 10 inches	124	40	71	Gas	S			
Do	4	27	25		....do	90		72	....do	S			
N. Root	4	27	25	1895	Bored, 6 inches	77	27	65	Wind	D			
W. H. Smith	4	27	25	1898	....do	72	24	63	....do	D			
Kern County Land Co	3	27	25		Bored, 10 inches	700	24	78	Gas	D, S			
Eli Bonnet	7	27	26	1905	Bored, 8 inches	120	69?		....do	D		120.00	
H. E. Phillips	23	27	26	1905	Bored, 7½ inches	142	105?		Horse	S		135.00	40
Pacific Coast Oil Co. [c]	32	27	26	1905	Bored, 8 inches	265	143		Steam	B			
Southern Pacific Co	15	28	26	1890?	....do	150	130?		Hand	D			
Kern County Land Co	28	27	25	1903	Bored, 10 inches	137	36	70	Gas	S			
Do	29	27	25	1903	....do	198	26	76	....do	S			
Delta school district	19	27	25		Bored, 6 inches	130	24	68	Hand	D			
A. Filben	18	27	25	1905	Bored, 10 inches	56	24	72	Gas	D	11	65.00	250
Palm Fruit Co	25	27	24		Bored, 12 inches	80	20	72	....do	I	15		
H. L. Weems	30	27	25		Bored, 6 inches	65	17		Wind	D, S			

[a] Cost of well and equipment combined.

[b] Yield estimated or statement of owner taken.

[c] Two wells.

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TABLE 62. *Records of wells in Kern County*—Continued.

Owner.	Location: Section	Location: Township (S.)	Location: Range (E.)	Year completed	Type and diameter of well.	Depth of well	Depth to water level	Tons per inch of water	Method of lift	Use of water	Yield	Cost of well	Cost of pumping plant
						Feet	Feet				Miner's inches		
Kern County Land Co.	9	28	26	1908	Bored, 10 inches	112	18	71	Gas				
Do	8	28	26	1903	do			71	do				
C. W. Rowles	4	28	23	1901	do	600±	0		Artesian				
Kern County Land Co	5	28	24	1899	Bored, 13 inches	600±	0	70	do		100		
Do	6	28	24	1899?	do	600±	0		do		70		
Do	8	28	24	1900	do	600±	0		do		70		
Mason & Son	24	28	24	1900	Bored, 11 inches	600±	0		do		100		
Mrs. E. Lewis	24	28	24	1902	Bored, 9 inches	500	0	70	do	S, I	40		
P. Solis	26	28	24	1897	do	444	0		do		4	6800 00	
C. B. Crawford	26	28	24	1904	Bored, 10 inches	400	0	74	do		90		
H. F. Laird	31	28	24	1898	Bored, 9 inches	450	0		do		25	1,000 00	
Tracy Bros	32	28	24	1898	do	507	0		do		25	1,200 00	
Do	32	28	24	1904	Bored, 11 inches	800	0		do		25	1,000 00	
O. E. Stimson	32	28	24	1895	Bored, 9 inches	450	0		do		25	1,000 00	
Tracy Bros	6	29	24	1901	Bored, 11 inches	707	0		do		25	1,000 00	
Miller & Lux	9	29	24		Bored, 7 inches	85	18		Horse				
Southern Pacific Co	18	29	24	1872	Bored, 8 inches	600		87	Steam	S, I			
Miller & Lux	27	29	25		do	85	107	68	Horse	S, I			
Southern Pacific Co	24	29	24	1901	Bored, 7 inches	101	38	87	Hand	S, I			
Miller & Lux	13	29	23		Bored, 12 inches		0	70	Artesian		40		
Do	30	29	24		Bored, 18 inches	800	50	87	Steam	S, I			
Do	30	29	24		Bored, 7 inches	40	0		Not raised				
Do	9	30	24		do	70	0		do				
Kern County Land Co	7	30	25		Bored, 8 inches	42	12		Horse				
Do	18	30	25		do	45	9		do				
Do	7	30	25	1900	Bored, 18 inches	90	8		Electric	S, I	11		
Do	8	30	25	1904	Bored, 6 inches	87	18	64	Horse	S, I			
Do	32	29	25	1908	do	48	16		do	S, I			
A. Presley	34	29	25		do	71	30	66	do				
Kern County Land Co	8	30	25	1904	do	46	15		do				
J. Knox	2	30	25	1905	do	70	16	69	Hand				
Rio Bravo Vineyard Co	27	29	25		Bored, 7 inches	80	17		Not raised				
J. O. McClellan	24	29	25		Bored, 13 inches	80	167		Steam		200	100.00	$1,000
H. H. Schultz	14	29	25	1905	do	94	16		do	I	250		
Do	14	29	25	1905	do	80			do	I	227		
Do	12	29	25	1905	do	95	18		do	I		80.00	
Kern County Land Co	5	29	25		Bored, 8 inches	61	6		Not raised	D, I			
Do	17	29	25		Bored, 7 inches		12		Horse	D, I			80

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Do	9	29	26		do		7	67	do	S			
G. T. Nighbert	32	28	26	1905	Bored, 13 inches	102	17		Steam	I	50		
E. A. David	21	29	26	1891	Bored, 6 inches	40	11	68	Horse	D, S			
Mr. George	15	29	26		do	75	11	68	Hand	D, S			
James Arthur	15	29	26		Bored, 7 inches	60	12	67	do	D, S			
Palm school district	15	29	26		Bored, 6 inches	44	7	72	do	D			
G. W. Michel	16	29	26		do	80	10		Wind, hand	D, S			
Kern County Land Co.[?]	15	29	26		Bored, 7 inches	65	12	71	Hand	S			
Kern County Land Co	10	29	26		Bored, 8 inches	39	31		Horse	S		30.00	
W. H. Baker	11	29	26	1897	Bored, 6 inches	40	20	71	Hand	D			
Kern County Land Co	26	28	26		Bored, 7 inches	100+	40		Not raised	N			
Do	25	28	26		Bored, 8 inches	51	31		do	N		45.00	
Do	1	29	26		Bored, 7 inches		19		Horse	D			
J. C. Roberts	6	29	27	1893	Bored, 6 inches	65	25		Hand	N			
Norris school district	8	29	27		Bored, 8 inches	36	25		do	D			
S. G. Rex	8	29	27	1889	Bored, 6 inches	82	23	69	do	D, S			
W. J. Heath	9	29	27		do	80	22?	69	do	D			
Kern County Land Co	14	29	27		Bored, 8 inches	82	28		Wind	D, S			
J. M. McIntosh	14	29	27	1905	Bored, 10 inches	55	35	70	Hand	D			
Mrs. M. Nichols	13	29	27		Dug, 4 feet	29	24		Wind	D, S			
T. A. Wells	12	29	27	1902	Dug, 3 by 6 feet	72	67		Gas	D, S			
Eastern Consolidated Oil Co	12	29	27	1903	(c)	71	56		Steam	B	26		
J. A. Montgomery	12	29	27	1905	(d)	122	84		Gas	I			
Monte Cristo Oil Co [e]	5	29	28	1903	Bored, 9¾ inches	280 320	180 210		Steam	B			
Pacific Coast Oil Co	7	29	28	1901	Bored, 14 inches	200	40		do	D, I	a 12		
Associated Oil Co.[f]	34	28	28	1900	Bored, 13 inches	80							
Do	34	28	28	1900	do	40							
Do	34	28	28	1900	do	35	10		do	B	a 4		
Do	34	28	28	1900	do	30							
Miller & Lux	1	29	28		Bored, 10 inches		0	90	Artesian	N	35		
J. Barker	5	29	29	1893	Bored, 6 inches	1,300	0	87	do	N	2		
Do	5	29	29	1893	Bored, 10 inches	400	0	92	do	N	30		
E. S. Jewett	18	29	28		Dug, 4 by 4 feet	22	20		Not raised	N			
E. M. Roberts [g]	13	29	27	1898	Bored, 15 inches	30	8		Steam	I	250		b 3,000
Do [i]	13	29	27	1902	do	40	6		do	I	350		2,500
Do	13	29	27	1878	Bored, 12 inches	30	18		Gas	D			140
Mrs. M. Owmans	19	29	28		Bored, 6 inches	27	5	69	Hand	D			
Union Ice Co	19	29	28	1903	Bored	36	13	68	Steam	Ice	a 23		
Sumner Water Co	21	29	28	1893	Dug, 7 by 9 feet; bored, 10 inches.	400	100		do	D	55		
C. C. Pierce	23	29	27	1888	Bored, 6 inches	23	8	68	Hand	D, S			
C. E. Greeley	23	29	27	1893	Bored, 7 inches	30	5		Horse	D			
Kern County Land Co.[i]	22	29	27	1898	Bored, 13 inches	51	3		Electric	I	200		
D. M. Elliott	21	29	27	1893	Bored, 6 inches	61	14	62	Hand	D			
J. O. Bolender	21	29	27		Bored, 7 inches	35	10	68	do	D			
Kern County Land Co	16	29	27		Bored, 13 inches	57	23		Horse	S		55.00	57
N. Peters	21	29	27	1894	Bored, 6 inches	61	24		Hand	D, S			

a Yield estimated or statement of owner taken.
b Two wells.
c Dug 56 feet and bored 15 feet by 10 inches diameter.
d Dug 74 feet and bored 48 feet by 9¾ inches diameter.
e Three wells.
f Four wells.
g Nine wells.
h Cost of well and equipment combined.
i Five wells.

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TABLE 62.—*Records of wells in Kern County*—Continued.

Owner.	Location. Section.	Township south.	Range east.	Year completed.	Type and diameter of well.	Depth of well.	Depth to water level.	Temperature of water.	Method of lift.	Use of water.	Yield.	Cost of well.	Cost of machinery.
						Feet.	*Feet.*	°*F.*			*Miner's inches.*		
Kern County Land Co.	20	29	27	.....	Bored, 6 inches	35	8	64	Hand	D			
Do.[a]	20	29	27	1899	Bored, 13 inches	90	13	.....	Electric	I	175		
Do.[a]	17	29	27	1899	do	120	16	.....	do	I	250		$3,500
Do	17	29	27	1892	Bored, 7 inches	76	14	69	Gas	D	1		
J. G. Derlw	19	29	27	1903	Bored, 6 inches	50	9	.....	Wind	D			
Hans Madson	19	29	27	1904	do	36	9	68	Wind, hand	D, S			
F. D. Lowe	19	29	27	1904	Bored, 10 inches	50	8	68	Hand	D			
M. F. Clandino	19	29	27	1904	Bored, 7 inches	20	9	68	do	D, S			
Mrs. C. B. McCleod	19	29	27	1894	Bored, 10 inches	48	16	69	Wind, hand	D, S			
Solomon Jewett	18	29	27	.....	Bored, 6 inches	33	8	.....	Hand	D, S			
Edward Wright	13	29	26	.....	Bored, 7 inches	68	12	68	do	D			
A. E. Burr	13	29	26	1895	do			.....	Wind	D			
Kern County Land Co.[a]	14	29	26	1900	Bored, 13 inches	107	16	.....	Electric	I	275		
Mrs. Johnson	22	29	26	.....	Bored, 6 inches	75	14	.....	Wind	D, S			
L. G. Helm	23	29	26	1901?	do	64	17	.....	Hand	S			4
G. Meuser	23	29	26	.....	do	60	77	67	do	D		$45.00	8
E. F. Beck	21	29	26	.....	Bored	60	107	64	do	D		45.00	4
John Karr	21	29	26	.....	do	55	10	64	do	D		40.00	4
Antonio Wegis	28	29	26	.....	Bored, 6 inches	90	127	66	Horse	D		70.00	25
John Frey	29	29	26	1905	Bored, 8 inches	27	13	.....	do	D		40.00	100
I. W. Harbaugh	29	29	26	1899	do	46	15	.....	Hand	D		46.00	75
S. B. Kingsley	26	29	26	.....	Bored, 6 inches	39	13	.....	Steam	D		80.00	450
Wiley Smith	26	29	26	1897	Bored, 8 inches	49	10	67	Hand	D, S			
B. T. Dewey	26	29	26	1901	Bored, 12 inches	80	8	.....	Electric	I	225		$3,500
Mr. Kelso	25	29	26	.....	Bored, 6 inches	35	8	68	Hand	D, S			
Kern County Land Co.[a]	30	29	27	1901	Bored, 13 inches	115	16	.....	Electric	I	200	80.00	
W. E. Dargie[c]	30	29	27	1904	do	148	6	.....	do	I			3,500
Do	30	29	27	1904	Bored, 10 inches	148	6	.....					
Do	30	29	27	1901	Bored, 12 inches	98	8	.....	do	I	250		$3,000
P. D. Jewett[d]	32	29	27	1904	Bored, 13 inches	80	7	.....	do	I	250		
Kern County Land Co.[a]	29	29	27	1901	do	87	11	.....	do	I	200		
Do	29	29	27	1898	do	69	9	.....	do	I	150		
Do.[c]	29	29	27	1898	do	71	9	.....	do	I	200		
Do.[d]	24	29	27	1900	do	71	1	.....	do	I	200		
Do.[a]	24	29	27	1897	do	61	10	.....	do	I	187		
Do.[a]	24	29	27	1898	do	70	7	.....	do	I	175		
Do	26	29	27	1899	do	69	5	.....	do	I	187		
Do	34	29	27	.....	Bored, 10 inches	56	8	.....	Horse	D			

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W. Winter	35	29	27	1904	Bored, 6 inches	20	4	60	Hand	D			
D. D. Hill	36	29	27		do	35	7	62	do	D			
C. C. Stockton	36	29	27	1890	Bored, 8 inches	45	8	62	Wind	D			
A. C. Tibbett	36	29	27		Bored, 6 inches	41	3	62	Hand	D, S			
D. R. Miller	1	30	27	1902	do	40	12	62	do	D, S		40.00	
James Lamb	6	30	28	1893	do	56	4	60	do	D			
Electric Water Co.[a]	25	29	27	1899	Bored, 13 inches	56	12		Electric	D	67		
Do	30	29	28		do	58	10		do	D	67		
Do	25	29	27	1902	do	56	8		do	D	67		
Do.[a]	30	29	28	1901	do	58	10		do	D	67		
Do	30	29	28	1904	do	66	4		do	D	67		
Do	30	29	28	1904	do	66	10		do	D	67		
Do	31	29	28	1903	do	56	10		do	D	67		
T. P. Pinnell	32	29	28	1897	Bored, 6 inches	39	24?		Wind	D			
Sumner Water Co	29	29	28	1903	Bored, 10 inches	175	26	68	Steam	D	74	300.00	
Mr. Patent	28	29	28		Bored, 6 inches	70	30		Not raised	N			
Chamberlin Canning Co	28	29	28		do	60	30		Wind, steam	D			
Chas. Offer	27	29	28	1896	Bored, 10 inches	90	30		Steam	I	150		
Do	27	29	28	1896	do	170	30						
Kern Fruit and Berry Co	28	29	28	1904	do	110	80	76	Gas	I	11		?1.150
Frank Morrison	34	29	28	1896?	Bored, 6 inches	45	31		Not raised	N			
H. A. Bobby	35	29	28		do	250	23	74	Wind	D, S			
Mrs. E. C. Morley	35	29	28	1901	Bored, 4 inches	240	27	73	Gas	D		300.00	150
Mr. Sturdevant	36	29	28		Bored, 8 inches	61	36	64	Hand	N		50.00	8
H. J. Nelkirk	35	29	28	1898	Bored, 24 inches	84	34?	65	Horse	D, S		46.00	10
J. F. Buckles	1	30	28		Bored, 6 inches	80	35		do	D		60.00	25
C. E. Hess	34	29	28		Bored, 13 inches	96	15		Not raised	N		375.00	
Mrs. E. C. Scott	34	29	28	1897	Bored, 5 inches	75	12		Hand	N			
A. J. Owens	33	29	28	1905	Bored, 8 inches	85	14	66	do	D		65.00	4
J. T. Bayse	33	29	28	1892	Bored, 6 inches	125	20?	64	Wind	D		133.00	35
Cemetery	32	29	28		do	73	10	74	Electric	I			
A. Amourig	5	30	28	1895	Bored, 5 inches	85	9.5		Hand	D, S			
D. Mungai	32	29	28	1904	Bored, 8 inches	40	8		Horse	D, I		30.00	80
Mrs. Wildman	6	30	28		Bored, 7 inches	60	14	67	Wind, hand	D, S			
Wm. Baker	6	30	28	1900?	Bored, 8 inches	112	17	66	do	D, S			
J. W. Overall	8	30	28	1892?	Bored, 6 inches	66	15	64	Hand	D, S		50.00	4
W. T. Jameson	4	30	28	1890	Bored, 8 inches	50	10		Horse	D, S		50.00	75
Eugene Verdier	4	30	28		Dug, 5 by 5 feet	10	7	61	do	S		20.00	10
A. J. Gilman	1	30	27	1904	Bored, 8 inches	70	10	62	Gas, hand	D, S, I		60.00	200
I. A. Hiatt	1	30	27	1900?	Bored, 6 inches	18	6	60	Hand	D			
C. C. Stockton	2	30	27		do	64	6		Steam	D, S			
L. M. Keith	2	30	27		do	33	13		Hand	D			
Coffee & Glenn	2	30	27	1904	Bored, 8 inches	36	11	62	do	D			
Christ Mattly	2	30	27	1902	Bored, 6 inches	26	4	62	Gas	D	5		325
T. H. Dickey	11	30	27	1902	Bored, 2 inches	25	8	62	Hand	D			
Kern County Land Co	5	30	27	1904	do	25	10	62	do	D		7.00	
W. S. Tevis	4	30	27	1882?	Bored, 7 inches	450	7	68	Electric	D, I	49		

[a] Four wells.
[b] Cost of well and equipment combined.
[c] Three wells.
[d] Five wells.
[e] Two wells.

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TABLE 62.- *Records of wells in Kern County* Continued.

Owner.	Location. Section.	Township south.	Range east.	Year completed.	Type and diameter of well.	Depth of well.	Depth to water level.	Temperature of water.	Method of lift.	Use of water.	Yield	Cost of well	Cost of installation
						Feet.	*Feet.*	°*F.*			*Miner's inches*		
Kern County Land Co.[a]	4	30	27	1899	Bored, 13 inches	70	10		Electric		1,0		
Do.[b]	4	30	27	1899	do	60	7		do		1,0		
Do.[a]	4	30	27	1899	do	113	7		do		900		
Do	8	30	27	1899	do	61	9		do		900		
Do	5	30	27	1899	do	120	9		do		1,0		
Do.[c]	6	30	27	1898	do	70	9		do		Inf		
Do.[d]	6	30	27	1899	do	151	9		do		1,0		
	6	30	27		do	140	9		do				
Do.[a]	6	30	27	1900	do	96	12		do		1,0		
Do	3	30	26	1901	do	80	8		do		1,0		
Do	3	30	26	1899	do	101	11		do		900		
Do	4	30	26	1899	do	91	6		do		900		
Do	4	30	26	1901	do	87	6		do		900		
Do	4	30	26	1901	do	71	7		do		900		
Do	4	30	26		Bored, 6 inches	48	12		Horse	M			
Do	3	30	26		do	43	15		do	M			
Do	4	30	26		do	44	14	68	do	M			
Do	5	30	26		do	45	14		do	M			
Do	7	30	26		do	50	14		do	M			
Do	8	30	26		do	42	13	64	do	M			
Do	6	30	26		do	45	15		do	M			
Do	1	30	25		do	62	16		do	M			
Do	11	30	25	1897	do	40	10		do	M			
Do	16	30	25		Bored, 8 inches	42	12		do	M			
Do	20	30	25		Bored, 6 inches	50	14	64	do	M			
Do	20	30	25		do	50	14	62	do	M			
Do	20	30	25		Bored, 8 inches	50	14	63	do	D, M			
Do	27	30	25		Bored, 6 inches	60	12		do	M			
Southern Pacific Co.	16	30	26		Bored, 8 inches	68	10	70	Steam	D	M		
C. D. Campbell	24	30	26	1901	Bored, 6 inches	45	13	72	Hand	D		$2,000.00	
Mrs. M. E. O'Hare	30	30	27	1895	do	68	12	68	Horse	D, M			
Kern County Land Co.	19	30	27		do	55	10	68	do	D, M			
A. Williamson	30	30	27	1891	do	62	8	66	Hand	D			
Kern County Land Co.	29	30	27	1905	do	52	8	64	do	D		95.00	60
W. W. Frazer	20	30	27		do	50	10	66	do	D			
M. Reddy	18	30	27		do	70	4	68	do	D			
Frezar Bros.	25	30	27	1899	do	40	8	64	Horse	D, M		40.00	
C. Mattly	32	30	27	1898	do	40	5	64	Hand	D, S			

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D. McNee	27	30	27	.....	....do	42	6	64	....do	D, S	.....	.....	.....
Miller & Lux	23	30	27	.....	Bored, 7 inches	66	5	64	....do	D	.....	.....	.....
H. H. Gillum	23	30	27	1899?	Bored, 6 inches	15	5	60	....do	D, S	.....	20.00	.....
J. A. Shafter	13	30	27	.....	....do	40	9	64	....do	D	.....	.....	.....
W. Orchard	14	30	27	.....	Bored, 8 inches	73	9	64	....do	D	.....	.....	.....
C. Kerr	14	30	27	1896	Bored, 6 inches	96	8	62	Horse	D, S	.....	15.00	3
A. G. Lial	15	30	27	.....	....do	35	5	64	Hand	D	.....	.....	.....
Manual Gonzales	11	30	27	1904	Bored, 2 inches	16	6	62	....do	D	.....	40.00	3
H. F. Banks	11	30	27	1903	Bored, 1¼ inches	12	7?	62	....do	D, S	.....	.....	.....
T. S. Fultz	12	30	27	1903	.....	40	5	62	Gas	D, S	10	.....	150
T. A. Moncure	12	30	27	.....	Bored, 6 inches	54	8	58	Wind	D	.....	.....	.....
W. T. Davis	7	30	28	1904	Bored, 10 inches	42	6?	64	Hand	D	.....	75.00	.....
P. C. Castro	13	30	27	1903	Bored, 6 inches	72	7	61	Horse	D	.....	54.00	50
C. F. Haperkern	18	30	28	1903	Bored, 7 inches	72	12	66	Hand	D	.....	.....	.....
Mrs. John Drow	13	30	27	.....	Bored, 6 inches	23	5	66	....do	D, S	.....	.....	.....
M. F. Silver	18	30	28	1896	....do	42	.....	66	....do	D	.....	33.00	3
Union Avenue school district	18	30	28	1893	....do	73	12?	64	....do	D	.....	55.00	4
Geo. A. Rankins	8	30	28	1905	....do	101	8?	64	....do	D	.....	90.00	.....
Geo. J. Frey	18	30	28	1902	....do	51	12?	64	.....	D, S	.....	25.00	3
J. E. Mills	17	30	28	1897	Bored, 8 inches	85	8	.....	Horse	S	.....	.....	.....
J. E. McCaffery	16	30	28	.....	Bored	40	5	.....	Gas	D	.....	.....	200
Jim Bernard	21	30	28	.....	Bored, 6 inches	18	6	60	Hand	D	.....	.....	3
Fairfax school district	11	30	28	.....	....do	+100	19	66	....do	D	.....	.....	4
P. Mill	12	30	28	.....	....do	.....	27	78	Horse	D	.....	.....	25
Mr. Mocettini	12	30	28	.....	Bored, 7 inches	62	22	.....	Not raised	N	.....	.....	.....
W. H. Muller	12	30	28	1898	Bored, 10 inches	70	28?	66	Horse	D	.....	90.00	7
Do	12	30	28	1905	....do	125	26?	.....	.....	N	.....	125.00	.....
J. W. Ingram	13	30	28	.....	Bored, 6 inches	65	41	.....	Horse	S	.....	.....	.....
M. Yancy	13	30	28	1895	Bored, 7 inches	125	60?	63	Wind	D	.....	125.00	300
Lee Berges	13	30	28	1903	Bored, 6 inches	62	39	67	Horse	D	.....	50.00	10
J. P. Schonetti	24	30	28	1903	....do	51	40?	67	....do	D	.....	50.00	15
A. W. Wells	25	30	28	1895	....do	51	30	67	Hand	D	.....	40.00	.....
James Fix	36	30	28	1899	....do	68	25	84	Horse	D	5	50.00	25
W. B. Myers	31	30	29	1896	Bored, 7 inches	68	24?	.....	Wind	D	.....	50.00	100
V. Moppin	30	30	29	1901	Bored, 6 inches	50	34?	.....	Not raised	N	.....	40.00	.....
F. J. Kincaid	32	30	29	1895	Bored, 7 inches	66	44	67	Hand	D	.....	50.00	9
D. Donavan	6	31	29	.....	Bored, 8 inches	44	42	66	....do	D	.....	35.00	2
J. T. Bate	36	30	28	1905	Bored, 9½ inches	194	30?	.....	Gas	I	.....	435.00	2,000
John McCaffrey	21	30	28	1894	Bored, 8 inches	83	7?	62	Hand	D, S	.....	20.00	3
John O'Neil	19	30	28	1895	....do	60	8?	.....	Wind	D, S	.....	25.00	.....
W. M. Hall	30	30	28	1901	.....	45	30?	65	Hand	D	.....	22.00	5
S. Hamilton	30	30	28	1895	Bored, 6 inches	52	12	70	....do	D	.....	.....	.....
Fairview school district	24	30	27	.....	....do	73	6.5	65	....do	D	.....	.....	.....
Jacob A. Shafter	24	30	27	1903?	....do	46	4.5	62	Gas	D, S	.....	30.00	600
C. Holtby	24	30	27	.....	....do	30	5	62	Hand	D	.....	.....	.....
Jean Pomroy	23	30	27	.....	Bored, 7 inches	55	7	62	....do	D	.....	.....	.....
C. L. Dennen	25	30	27	1899	Bored, 6 inches	36	6	61	....do	D	.....	.....	.....
Do	25	30	27	1904	....do	85	5	60	....do	D	.....	.....	.....
Mrs. Allen	25	30	27	1904?	....do	107	3?	66	....do	D, S	.....	80.00	.....

[a] Four wells. [b] Five wells. [c] Three wells. [d] Two wells.

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TABLE 62. *Records of wells in Kern County* Continued.

Owner.	Location. Section.	Township south.	Range east.	Year completed.	Type and diameter of well.	Depth of well.	Depth to water level.	Temperature of water.	Method of lift.	Use of water.	Yield.	Cost of well	Cost of machinery.
						Feet.	*Feet.*	°*F.*			*Miner's inches.*		
Alexander Berges	30	30	28	.....	Bored, 6 inches.	60	6	67	Hand	D.		.....	
W. M. Beckman	29	30	28	1900	Bored, 8 inches	90	87	.....	Gas	D, M		.....	$400
C. D. Morris	31	30	28	1904	Bored, 6 inches	60	6	61	Hand	D.		$40.00	4
Charley Chung	32	30	28	1901	Dug, 4 by 4 feet	11	9	62	do	D		.....	
R. R. P. Fox	30	30	28	.....	Bored, 6 inches	100	8	70	Gas	D	2	.....	
J. G. McKee	36	30	27		do	91	7	68	Hand	D.			
O. Burton	35	30	27		do	44	8	66	do	D			
R. E. Houghton	31	30	28	.....	do	65	107	66	do	D		35.00	10
P. M. Wilkerson	30	30	27	1902	Bored, 2 inches	52	8	64	do	D		27.00	
S. Curnel	25	30	27	1902	Bored, 6 inches	45	8	64	do	D		30.00	
M. L. Replogle	30	30	27		Bored, 8 inches	90	6	70	do	D, M			
H. A. Emerson	36	30	27	1902	Bored, 6 inches	50	10	64	Horse	D, M		25.00	75
S. Stillson	35	30	27	1904	Bored, 7 inches	80	9	66	Gas	D, M	11		
A. A. Doyle	35	30	27	1904	Bored, 6 inches	50	10	66	Hand	D			
J. W. Parish	8	31	27	1902	do	40	12	66	do	D, M			
Christ Ruedy	34	30	27	1901	Bored, 8 inches	64	8	68	Steam	D, M	0	30.00	85
E. F. Pyle	34	30	27	1902	do	71	10	62	Gas		55	40.00	30
Do	3	31	27	1900	Bored, 6 inches	20	8	67	Hand	M		12.00	
Mrs. A. H. May	4	31	27	1900	do	60	6	67	do	D		30.00	
E. M. Ashe	34	30	27	1902	do	67	12	72	Horse	D, M		60.00	
H. R. Freear	29	30	27	1902	do	45	7	64	Wind	D, M			
J. B. McCutchen	29	30	27	1900	do	42	8	62	Hand	D			
J. Adams	32	30	27	1902	Bored	60	.....	64	Horse	D, M			
V. Stoner	32	30	27	1907	Bored, 8 inches	800	0	72	Artesian	D, M	Small.	2,400.00	
M. F. Pearson	29	30	27	1908	Bored, 6 inches	62	9	67	Hand	D		30.00	4
V. Stoner	30	30	27	1904	Bored, 12 inches	200	.....	66	Steam		200		
Do	30	30	27	1908	Bored, 8 inches	86	6	68	do	D, M	8	40.00	
H. W. Jackson	31	30	27	1900	Bored	67	8	68	Hand	D			
Kern County Land Co	36	30	26		Bored, 10 inches		0	70	Artesian	S			
Do	26	30	26		do	950	0	72	do	S	2		
Do	34	30	26		Bored, 8 inches	+800	0	69	do	S	3		
Do	31	30	26		do		0	70	do	S			
Do	11	31	25		Bored, 6 inches	305	0	80	do	S			
Do	17	31	26		Bored, 8 inches	312	0	84	do	S			
G. Barker	1	31	26		Bored, 6 inches		0	75	do	D, S			
H. Piper	28	31	26		do	40	5	66	Horse			20.00	75
J. S. Ellis	6	31	27	1907	Bored	50	7	68	Steam	D	20	25.00	30
C. Mattly	12	31	26		Bored, 4 inches	500	0	70	Artesian	S	4		

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Do	12	31	26	.....	Bored, 8 inches	500	0	74	....do	S	22	.....	.....
Kern County Land Co	7	31	27	.....	Bored, 6 inches	.....	0	77	....do	S	.....	.....	.....
P. Corti	18	31	27	1900	Bored, 10 inches	30	10	64	Horse	.....	.....	39.00	50
T. Corsett	8	31	27	.....	Bored, 6 inches	48	9	66	Hand	D	.....	.....	.....
J. Zumwaldt	6	31	27	.....	.....	59	11	68	....do	D	.....	.....	.....
R. S. Ash	6	31	27	1902	Bored, 6 inches	45	9	66	....do	D	.....	.....	.....
R. L. Emery	31	30	27	1897	Bored	57	9	68	....do	D	.....	.....	.....
J. Zumwaldt	32	30	27	.....	Bored, 6 inches	25	10	68	....do	D	.....	.....	.....
C. Baptista	5	31	27	1900	....do	48	9	68	....do	D	.....	25.00	4
C. Williams	5	31	27	.....	.....	54	12	68	....do	D	.....	27.00	6
J. Herod	4	31	27	.....	Bored, 6 inches	50	10	68	....do	D	.....	.....	.....
L. F. Johndrone	4	31	27	.....	....do	50	8	66	....do	D	.....	.....	.....
J. W. Webster	3	31	27	1890	....do	64	9	68	....do	D	.....	48.00	4
Mr. Jealy	10	31	27	.....	....do	62	9	67	....do	D	.....	.....	.....
J. Vernachio	1	31	27	1903	....do	50	10	64	....do	D, S	.....	.....	.....
O. R. Taylor	1	31	27	1901	....do	48	5	68	....do	D	.....	24.00	3
D. E. Josephi	7	31	28	1893?	Bored, 8 inches	150	.....	65	Wind	D, S	.....	150.00	80
Walter Abby	5	31	28	.....	Bored, 6 inches	33	2	64	Hand	D	.....	25.00	4
S. A. Williams	5	31	28	1904	....do	25	3.5	62	....do	S	.....	16.00	3
T. W. Glover	5	31	28	1901	....do	27	2	66	....do	D	.....	20.00	4
A. S. Taylor	9	31	28	1902	Bored	45	3?	66	....do	D	.....	20.00	3
R. E. Houghton	8	31	28	1903	Bored, 8 inches	156	0	66	Artesian	I	5	.....	.....
L. E. Formway	5	31	28	1902	Bored, 2 inches	28	10?	64	Hand	D	.....	6.00	10
N. H. Stoner	9	31	28	1901	Bored, 6 inches	112	0	66	Artesian	D	a 1	112.00	.....
R. E. Hoten	7	31	28	.....	....do	400	0	67	....do	S	4	.....	.....
C. D. Oldershaw	7	31	28	.....	....do	.....	3	.....	Horse	D	.....	.....	25
Tim Flannigan	17	31	28	1901	....do	100	1	67	....do	D	.....	75.00	20
F. A. Langdon	12	31	28	1904	Bored, 12 inches	240	15?	.....	Gas	I	.....	240.00	.....
A. J. Fowler	13	31	28	1904	Bored, 13 inches	53	16	.....	Not raised	N	.....	.....	.....
H. A. Blodgeth	12	31	28	1893	Bored, 7 inches	70	28	.....	Hand	D	.....	50.00	30
V. H. Plummer	12	31	28	.....	Bored, 6 inches	43	27	66	....do	D	.....	25.00	4
C. B. Alexander	7	31	29	1892	Bored, 8 inches	80	32?	.....	Horse	D	.....	60.00	.....
W. D. Knight	7	31	29	1901	Bored, 7 inches	82	30?	68	....do	D	.....	50.00	40
Mr. Deegan	18	31	29	.....	Bored, 10 inches	49	41	.....	....do	D	.....	.....	.....
F. T. Rosendahl	18	31	29	.....	....do	44	27	.....	....do	D	.....	.....	.....
J. C. Castle?	18	31	29	1899	Bored, 6 inches	55	20?	68	....do	D	.....	36.00	45
F. H. Langdon	20	31	29	1894	Bored, 8 inches	62	14?	.....	....do	D	.....	60.00	.....
J. Cuda	20	31	29	1897	Bored, 7 inches	55	20	66	Hand	D	.....	55.00	18
J. F. Bennett	20	31	29	.....	Bored, 6 inches	38	26	63	....do	D	.....	23.00	6
A. M. Towne	19	31	29	.....	Bored, 5 inches	1,040	9	.....	Not raised	N	.....	.....	.....
	22	31	29	.....	Bored, 7 inches	70	58	.....	Horse	N	.....	.....	.....
Richard Derdy	15	31	29	.....	Bored, 8 inches	73	68	.....	Not raised	N	.....	55.00	.....
A. J. Allen	23	31	29	.....	....do	+100	98	.....	Horse	N	.....	.....	.....
	24	31	29	.....	Bored, 7 inches	86	76	.....	...do	N	.....	65.00	25
G. H. Deacon	26	31	29	.....	Bored, 8 inches	57	56	.....	Not raised	N	.....	45.00	.....
M. E. Baker	26	31	29	.....	Bored, 7 inches	45	44.5	.....	Hand	D	.....	.....	.....
Fred Hill	34	31	29	1897	....do	48	30	.....	Horse	D	.....	35.00	20
J. Brockman	28	31	29	1890	....do	58	24	.....	Not raised	N	.....	45.00	.....
Beheran Domingo	28	31	28	1852	Bored, 8 inches	.....	2	.....	Horse	D	.....	.....	.....
Kern County Land Co	21	31	28	1875	....do	350	0	.....	Artesian	S	.....	.....	.....
Do	20	31	28	1887	Bored, 7 inches	900	0	70	....do	D	1	.....	.....

a Yield estimated or statement of owner taken.

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TABLE 62.—*Records of wells in Kern County*—Continued.

Owner.	Location.			Year completed.	Type and diameter of well.	Depth of well.	Depth to water level.	Temperature of water.	Method of lift.	Use of water.	Yield.	Cost of well.	Cost of machinery.
	Section.	Township south.	Range east.										
						Feet.	*Feet.*	°F.			*Miner's inches.*		
Chank	18	31	28	.....	Bored, 6 inches	80	4	66	Wind	D	.....	$60.00	$150
	19	31	28	1899	do	87	8?	63	Hand	D	.....	45.00	8
d Co	29	31	28	.....	Bored, 7 inches	.....	0	66	Artesian	S	.....	.....	.....
	32	31	28	.....	do	.....	0	66	do	S	3	.....	.....
	32	31	28	.....	do	.....	0	68	do	S	.....	.....	.....
	31	31	28	.....	do	.....	0	68	do	S	.....	.....	.....
	19	31	28	1903	Bored, 6 inches	80	3	68	Hand	D	.....	40.00	3
	24	31	27	.....	Bored, 8 inches	620	0	.....	Artesian	D, S	.....	.....	.....
	20	31	27	.....	Bored, 10 inches	650	0	76	do	S	.....	.....	.....
	19	31	27	1899	Bored, 12 inches	1,395	0	72	do	S	2	.....	.....
	25	31	26	.....	Bored, 6 inches	.....	0	74	do	S	.....	.....	.....
	28	31	26	.....	Bored, 10 inches	.....	0	78	do	S	.....	.....	.....
	32	31	26	1899	Bored, 4 inches	415	0	78	do	D, S	18	.....	.....
	6	32	26	1900	do	416	0	79	do	S	18	.....	.....
	4	32	26	1900	do	286	0	74	do	S	25	.....	.....
	2	32	26	1900	Bored, 6 inches	345	0	78	do	S	16	.....	.....
	6	32	27	.....	do	.....	0	77	do	S	.....	.....	.....
	6	32	27	.....	do	77	7	63	Horse	D, S	.....	.....	.....
	30	31	27	1898	Bored, 8 inches	645	0	74	Artesian	S	23	.....	.....
	9	31	27	1898	Bored, 4 inches	645	0	78	do	S	18	.....	.....
		31	27	.....	Bored, 10 inches	.....	0	73	do	D, S	3	.....	.....
		31	27	.....	Bored, 4 inches	.....	0	74	do	S	3	.....	.....
	3	31	27	.....	Bored, 10 inches	.....	0	74	do	S	8	.....	.....
	5	32	27	.....	do	.....	0	74	do	S	20	.....	.....
	4	32	27	1899	Bored, 2 inches	582	0	74	do	S	4	.....	.....
	3	32	27	.....	Bored, 6 inches	29	4	65	Horse	B, S	.....	20.00	30
	5	32	28	.....	Bored, 7 inches	.....	0	67	Artesian	.....	.....	.....	.....
	11	32	27	.....	Hydraulic, 4 inches	.....	0	70	do	S	.....	.....	.....
	15	32	27	.....	do	271	0	66	do	S	.....	.....	.....
Do	9	32	27	1902	Bored, 4 inches	507	0	74	do	S	2	.....	.....
Do	8	32	27	1897	Bored, 3 inches	378	0	74	do	S	3	.....	.....
Do	16	32	27	1904	Bored, 6 inches	648	0	74	do	D, S	7	.....	.....
Do	21	32	27	1900	Bored, 3 inches	896	0	75	do	S	3	.....	.....
Do	22	32	27	.....	Hydraulic, 2 inches	.....	0	65	do	S	.....	.....	.....
Do	13	32	27	.....	Hydraulic, 4 inches	.....	0	69	do	S	.....	.....	.....
	25	32	27	.....	do	.....	0	68	do	S	.....	.....	.....
	25	32	27	.....	do	.....	0	68	do	S	.....	.....	.....
	24	32	27	.....	Bored, 8 inches	.....	0	70	do	S	.....	.....	.....

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INDEX.

A.

Page.

Acids, effects of, in water 70
Alameda County, records of wells in 196
Alkali, occurrence of 52
permissible limits of 52–54, 56–58
remedies for troubles from 58–61
source of 51–52
Alkalies, relative harmfulness of 55
Alling, P., pumping plant of, test of 150
American Railway Engineering and Maintenance of Way Association, reports on boiler waters by 67–69
Analyses of ground water 134–138, 180–181, 198–199, 210–211, 227–228, 237–238, 255, 283, 292–294
Anderson, J. J., pumping plant of, test of 159
Artesian areas, ground-water levels, and pumping plants examined, map showing ..... In pocket
Axial waters, composition and quality of .. 117–119
suitability of, for industrial use 130, 131
for irrigation 125, 126

B.

Bacteria, precautions against, in water 74–75
Badger Irrigation Co., pumping plant of, test of 159
Beard, Mrs. William P., pumping plant of, test of 147–148
Bicarbonate, test of water for 42
See also Carbonate.
"Black alkali." *See* Carbonate.
Blacherne Water Co. pumping plant of, test of 157
Boiler compounds, character and use of 64–65
Boilers, ratings of waters for 65–69
troubles from water in, causes of 61–63
remedies for 63–69
Borden, pumping plants at, tests of 153–154
Briscoe, —, pumping plant of, test of 161
Buena Vista reservoir, water of, analysis of .. 96
Bunker, W. E., pumping plant of, test of 148

C.

Calaveras County, records of wells in 196
Calcium, effects of, in water 71–72, 76, 78–79
Calcium sulphate, deposition of 116–117
California Agricultural Experiment Station, analyses of waters by 134–138
Carbonate, effects of, in water 72, 78
test of water for 42
Charles, Dr. M. S., pumping plant of, test of. 163
Chlorine, content of, in artesian water 117–119
effects of, in water 72–73, 75–76, 77
test of water for 42
Coagulants, substances used as 86
Cold water, effect of irrigating with 127

Page.

Color, disadvantage of, in water 70, 74
Contra Costa County, records of wells in ... 194–196
Copo de Oro Water Co., pumping plant of, test of 158
Corrosion of boilers, causes of 62

D.

Denudation in the Sierra, rate of 97–98
Deposition in San Joaquin Valley, rate of 98–99
Depreciation of pumping plants, percentage of 166, 168
Depth, relation of, to mineral content 122–123
Development of the valley trough 19
Disinfection of water, means of 84
Distillate, price of 166
Domestic use, poor supplies for, depth and position of 132
requirements of water for 73–82
Drainage, removal of alkali by 60–61
Dutton, J. C., pumping plants of, tests of 143

E.

Eaton, F. M., analyses by 90–91
work of 39
East-side waters, composition and quality of 110–112
suitability of, for industrial use 128–129, 131
for irrigation 123–124, 126
Efficiency of pumping plants, mode of estimating 167
Exeter, pumping plants at, tests of 159–161

F.

Feed water, heating of 88–89
Filtration, rapid sand, description of 86–87
slow sand, description of 84–86
Fiske, A. J., jr., work of 212, 229, 295
Flooding, effect of, on alkali 58–60
Foaming in boilers, causes of 63
Food products, areas in the Southwest in which they can be produced 10
increasing demand for, in the Southwest. 9
Fresno, pumping plant at, test of 154–155
Fresno County, farming and irrigation in .. 234–236
flowing wells in 236–237
ground waters of, assays and analyses of 237–238
pumping in, cost of 235
records of wells in 239–251
waters of, analyses of 136–137, 139
Fuel oil, price of 166

G.

Gard, O. S., pumping plant of, test of 161
Geography of the valley 15–17
Geology, outline of 18–21
Girard, W. R., pumping plant of, test of 151

Digitized by Google

Page.
Ground water, accessibility of..... 30
analyses of.... 134–138, 180–181, 198–199, 210–211, 227–228, 237–238, 255, 283, 292–294
circulation of..... 28–29
collection of samples of..... 40–41
development of..... 30–32
field assay of..... 41–50
accuracy of..... 43–45
results of, compared with results of analyses..... 46–50
origin of..... 27
quantity of..... 29
quality of, important..... 38–39
substances tested for in..... 50–51
value of, for irrigation..... 32–37
Grunsky, C. E., on the history of Tulare Lake. 281
Gustine, pumping plants at, tests of..... 148–149

H.

Harding, S. T., and Robertson, Ralph D., on development of the ground water. 32
Hardness, test of water for..... 43
Hauschildt, G. H., pumping plant of, test of..... 163–164
Hieb, J. A., pumping plant of, test of..... 146
High, J. H., pumping plant of, test of..... 144
Hill, T. R., pumping plant of, test of..... 142–143
Hilo pump, test of..... 157
Hogan Bros., pumping plants of, tests of.. 150–151
House, Joe, pumping plant of, test of..... 149
Hydrogen sulphide, effects of, in water... 73, 74, 75

I.

Imperial Valley, benefit of irrigation to..... 10
Industrial use, requirements for 69–73
results of..... 130–131
suitability of water for..... 128–131
Industries, extent of..... 128
Iron, effects of, in water..... 70–71, 75
Irrigation, development of, in the Southwest. 9–13
suitability of ground water for... 32–37, 123–125
use of ground water for..... 31–32
value of ground water for..... 32–37
with cold water, effect of..... 127
with ground water, results of..... 125–127

J.

Job, R. W., pumping plant of, test of..... 156

K.

Kern County, flowing wells in..... 289–290
Kern County, ground water of, assays and analyses of..... 138, 139, 292–294
ground water of, sources of..... 289
pumping plants in..... 290–292
records of wells in..... 295–306
Kern River, water of, analyses of..... 91
Kettleman, George D., pumping plant of, test of..... 145
Kings County, flowing wells in..... 282
ground waters of, assays and analyses of.. 137, 139, 283
records of wells in..... 284–288
Kings River, development of ground water on..... 234–236
Kings River, monthly discharge of..... 26
wells north of, composition of water of.. 100–104
Kummis, Sam, pumping plant of, test of.... 147

L.

La Salle, A. S., pumping plant of, test of.. 143–144
Laurel Colony, pumping plant of, test of.... 163
Leach, J. H., pumping plant of, test of.... 158–159
Lift of pumps, limit of..... 170
Lindsay, pumping plants at, tests of..... 161–162
Lippincott, J. B., on irrigation with ground water in Fresno County..... 234–235
Lodi, pumping plants at, tests of.. 142–148, 150–151

M.

McAdams, F. S., pumping plant of, test of... 164
McAdams, W. J., pumping plant of, test of.. 164
McCreary, P. L., analyses by..... 90–91
McGee, W. J., work of..... 90–91
McGlashan, H. D., on the history of Tulare Lake..... 281
Madera, pumping plants at, tests of.... 152–153, 154
Madera County, farming and irrigation in.... 226
flowing wells in..... 226–227
ground waters of, assays and analyses of. 136, 139, 227–228
pumping plants in..... 227
records of wells in..... 229–233
Magnesium, effects of, in water..... 71–72, 76, 78–79
Martin, G. A., pumping plant of, test of..... 156
Martin, L. G., pumping plant of, test of..... 164
Means, Thomas H., work of..... 234
Merced, pumping plants at, tests of..... 151–152
Merced County, farming and irrigation in.. 208–209
flowing wells in..... 209
ground waters of, assays and analyses of. 136, 139, 210–211
pumping plants in..... 209–210
records of wells in..... 212–225
Merced River, water of, analyses of..... 91–93
Mesmer, Louis, work of..... 234
Micke, W. G., pumping plant of, test of..... 147
Mineral content of ground waters, diagram showing..... 120
increase of, from south to north..... 119–122
relation of, to depth..... 122–123
Mokelumne River, water of, analyses of..... 91
Municipal water supplies, composition of.. 133–134

O.

Organic matter, effects of, in water..... 73

P.

Pacific Coast Oil Co., treatment of boiler waters by..... 129–130
Packard, W. C., work of..... 90–91
Pate, S. M., pumping plant of, test of..... 152
Patterson, H. W., pumping plant of, test of.. 153
Patterson, pumping plant at, test of..... 149
Patterson Colony, pumping plant of, test of.. 149
Pogue, Tom, pumping plant of, test of..... 160
Pollution, possibility of..... 132
Portersville, pumping plants at, tests of... 155–159
Potability, rating of water as to..... 79–82
Powers, W. A., acknowledgment to..... 40

Digitized by Google

Page.
Precipitation, record of, in 1910 40-41
Preston, P. W., pumping plant of, test of.... 160
Priest, R. M., work of 212, 229
Pumping, cost of electric current for 34
Pumping machinery, large, expense of..... 168-169
overloading and underloading, waste in.. 170
overspeeding and underspeeding, waste in 171-172
selection of proper size of 174-176
Pumping tests, discussion of 168-176
tabulated results of 165-167
Pumps, cost of operating, against various static heads 173
of various sizes, time required for irrigation with 172

Q.

Quality of ground waters, means of forecasting 139-140
near Tulare Lake, map showing prospects for 108
summary of 140-141

R.

Rash, Charles, pumping plant of, test of... 145-146
Reinhart, William, work of 90-91
Rivers. *See* Streams.
Robertson, Ralph D., Harding, S. T., and, on development of the ground water. 32
Rocks of the border of the valley 18-20
Roderigs, Jesse, pumping plant of, test of.... 152
Roeding & Wood Nursery Co., pumping plant of, test of 162
Root, Dr. C. B., pumping plants of, tests of.. 161-162
Rosedale Water Co., pumping plant of, test of. 155

S.

Salt. *See* Chlorine.
San Joaquin County, flowing wells in..... 178
ground waters of, assays and analyses of 135, 139, 180-181
pumping plants in..... 178-180
records of wells in 183-194
San Joaquin River, water of, analyses of..... 91-93
San Joaquin valley, west side of, composition of well waters of 112-117
Sayre, A. L., pumping plant of, test of..... 152-153
Scale, formation of 61-62
Settlemire, D. C., pumping plant of, test of. 155-156
Shaw, L. W., pumping plant of, test of.... 160-161
Skaggs, S. W., pumping plant of, test of..... 154
Smith, S. M., work of 212, 229
Soda ash, use of, for softening water..... 76
Softening of water, means of..... 76, 87-88
Soils, origin of 22-23
problems concerning 11
relation of applied water to 55-56
surveys of 23
Solids, total, formula for estimating..... 81-82
Southern Pacific Co., procedure in analyses for 50
treatment of boiler waters by..... 129
Stabler Herman, formulas of, for rating boiler waters..... 65-67

Page.
Stanislaus County, flowing wells in..... 197-198
ground waters of, assays and analyses of..... 135, 198-199
pumping plants in..... 198
rainfall and surface waters of..... 197
records of wells in..... 200-207
Stanislaus River, water of, analyses of..... 91-93
Stanislaus Water Co., irrigation by..... 177
Stillman, Howard, acknowledgment to..... 40
Stockton & Mokelumne Irrigating Co., operations of..... 177
Streams, mean yearly run-off of..... 25
yearly discharge of..... 24
waters of, analyses of..... 90-93
Sulphate, content of, in ground waters, cross sections showing..... 102
content of, in ground waters, map showing..... In pocket
effects of, in water..... 72
test of water for..... 42-43
Sunnyside Water Co., pumping plant of, test of..... 158
Surface of the valley, building of..... 20-21
Surface waters, chemical composition of..... 90-99
volume of..... 23-26
Suspended matter in water, effects of..... 70, 73-74

T.

Tindell, P. H., pumping plant of, test of... 144-145
Tretheway, John, pumping plant of, test of.. 146
Tulare, pumping plants at, tests of..... 163-164
Tulare County, flowing wells in..... 252
ground waters of, assays and analyses of..... 137, 139, 255
permanence of..... 253-255
sources of..... 252
pumping plants in..... 253
records of wells in..... 256-280
Tulare Lake, history of..... 281-282
water of, analyses of..... 94-96
wells near, composition of water of.... 104-109
proper depth of..... 108-109
wells south of, composition of water of. 109-110
Tuolumne River, water of, analyses of..... 91-93
Tyler, E. P., pumping plant of, test of..... 151

U.

United States Geological Survey, investigations of ground waters by..... 13-15
United States Reclamation Service, analyses of well waters by..... 139

V.

Valle-Verde Investment Co., pumping plant of, test of..... 154-155
Van Winkle, Walton, analyses by..... 90-91
work of..... 39

W.

Wagner, Jacob, pumping plant of, test of.... 148
Walters Bros., pumping plant of, test of..... 154
Water, applied, relation of, to soils..... 55-56
distillation of, apparatus for..... 83
mineral, potability of..... 76-79
purification of, demands on..... 82-83
methods of..... 83-88
turbid, effects of..... 70

Digitized by Google

Page.
Wells around Tulare Lake, water of, composition of 104–109
flowing, data on 36
location and depth of, in relation to sulphate content of ground waters, map showing ..... In pocket.
north of Kings River, water of, composition of 100–104
of east side of valley, water of, composition of 110–112
Wells, records of 183–196
south of Tulare Lake, water of, composition of 109–110
West-side waters, composition and quality of 113–117
suitability of, for industrial use 129–130, 131
for irrigation 124–125, 126
White, W. N., work of 182, 200, 212
Windmills, use of, in San Joaquin County .. 179–180
Woodbridge Canal & Irrigation Co., operations of 177

O

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PAT. 1,290,083 PAT. 1,593,048
THE UNITED STATES ENVELOPE CO. SPRINGFIELD, MASS.
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GEOLOGY AND GROUND WATERS OF NORTHEASTERN ARKANSAS

BY

LLOYD WILLIAM STEPHENSON

AND

ALBERT FOSTER CRIDER

WITH A DISCUSSION OF

THE CHEMICAL CHARACTER OF THE WATERS

BY

RICHARD B. DOLE

WASHINGTON
GOVERNMENT PRINTING OFFICE
1916

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CONTENTS.

	Page.
Introduction	13
Physiographic provinces of Arkansas	13
Acknowledgments	14
Bibliography	15
Physiography	22
Classification of features	22
Coastal Plain uplands	22
Coastal Plain lowlands	25
Advance lowland	25
Mississippi lowland	28
Small mounds	30
Geology	31
General composition and structure of the area	31
Paleozoic rocks	32
Mesozoic and Cenozoic formations	34
Generalized section	34
Cretaceous system	34
Igneous intrusions of late Lower Cretaceous or early Upper Cretaceous age	34
Upper Cretaceous series	35
Character and distribution	35
Nacatoch sand (?)	36
General features	36
Local details	37
Independence County	37
South of Independence County	40
Correlation	41
Cretaceous strata penetrated in wells and excavations	42
Tertiary system	44
Distribution	44
Eocene series	44
Formations differentiated	44
Midway formation	45
General features	45
Local details	48
Pulaski County	48
Lonoke County	49
White County	49
Jackson County	51
Independence County	53
Correlation	53

Digitized by Google

Geology—Continued.
Mesozoic and Cenozoic formations—Continued.
Tertiary system—Continued.
Eocene series—Continued. Page.
Wilcox formation 54
General features 54
Local details 57
Missouri 57
Clay County 57
Greene County 58
Craighead County 60
Exposures of quartzite 61
Poinsett County 61
Correlation 63
Claiborne formation 63
General features 63
Local details 67
Spencer Creek, Cross County 68
Cherry Valley section, Cross County 68
Sections east of Wynne, Cross County 70
Copperas Creek section, Cross County 71
Correlation 72
Jackson formation 73
General features 73
Local details 75
St. Francis County 76
Phillips County 78
Arkansas River localities 79
Correlation 82
Undifferentiated Eocene 84
Pliocene series 85
Lafayette formation 85
General features 85
Local details 89
Clay County 89
Greene County 90
Craighead County 91
Poinsett County 91
Cross County 92
St. Francis County 93
Lee County 94
Phillips County 94
Western border of the Mississippi embayment 95
Correlation 97
Quaternary system 100
Pleistocene series 100
Loess 100
Areal distribution 100
Stratigraphic position 101
Lithologic character 101
Thickness 105
Physiographic expression 105
Paleontologic character 105

Digitized by Google

Geology—Continued.
Mesozoic and Cenozoic formations—Continued.
Quaternary system—Continued.
Pleistocene series—Continued.
Loess—Continued. Page.
Local details.... 106
Helena, Phillips County.... 106
Forrest City, St. Francis County.... 107
Wynne, Cross County.... 108
Jonesboro, Craighead County.... 110
Greene County.... 110
Clay County.... 111
Western margin of the Mississippi embayment in Arkansas.... 111
Correlation.... 112
Alluvium.... 114
General features.... 114
Local details.... 116
Cloverbend, Lawrence County.... 116
Old Grandglaise, Jackson County.... 116
Colona, Woodruff County.... 117
Augusta, Woodruff County.... 117
Phillips County.... 118
Logs of wells.... 118
Correlation.... 120
Recent series.... 121
Undifferentiated Quaternary alluvium.... 122
Geologic history.... 123
Deposition of Paleozoic sediments.... 123
Post-Paleozoic erosion interval.... 123
Depression in Lower Cretaceous time.... 123
Depression and deposition in Upper Cretaceous time.... 124
Uplift and erosion between the Cretaceous and Eocene.... 124
Depression and deposition in Eocene time.... 124
Post-Eocene erosion.... 126
Deposition of the Lafayette formation.... 126
Post-Lafayette erosion interval.... 127
Deposition of the loess.... 127
Erosion of the great troughs west and east of Crowleys Ridge and deposition of Pleistocene alluvium.... 129
Captures of Mississippi River by Ohio River.... 131
Deposition of Recent alluvium.... 132
Late Pleistocene and Recent erosion.... 132
Surface waters.... 132
Streams.... 132
Lakes and ponds.... 133
Swamps.... 133
Economic uses.... 134
Ground waters.... 134
Source.... 134
Disposal.... 135
Quantity.... 135
Stratigraphic distribution.... 136
Cretaceous deposits.... 136

Digitized by Google

Ground waters—Continued.
Stratigraphic distribution—Continued. Page.
Tertiary deposits 136
Eocene strata 136
Lafayette formation (Pliocene ?) 138
Quaternary deposits 138
Springs 139
Nonartesian waters 139
Definition and importance 139
Methods of development 139
Artesian waters 140
Definition 140
General conditions governing occurrence 140
Conditions in the Advance lowland 141
Conditions in the Mississippi lowland 142
Economic uses 143
General uses 143
Rice culture 144
History 144
Production 145
Outlook 146
Water supply 146
Soil 147
Duty of water 148
County descriptions 149
Arkansas County 149
Physiography 149
Geology 150
Water resources 150
General conditions 150
Domestic supplies 150
Irrigation 150
Local supplies 151
Stuttgart 151
Irrigation wells 152
Clay County 160
Physiography 160
Geology 161
Water resources 162
General conditions 162
Local supplies 162
Source 162
Well water for irrigation 163
Well at Campbell, Mo 163
Craighead County 166
Physiography 166
Geology 167
Water resources 168
General conditions 168
Domestic supplies 168
Irrigation 168
Local supplies 169
Jonesboro 169
Nettleton 170

Digitized by Google

County descriptions—Continued.
Craighead County—Continued.
Water resources—Continued.
Local supplies—Continued. Page.
Greensboro 170
Lake City 170
Wells for irrigation 170
Crittenden County 174
Physiography 174
Geology 174
Water resources 175
General conditions 175
Local supplies 175
Earl 175
Turrell 175
Wells at and near Memphis, Tenn 176
Cross County 179
Physiography 179
Geology 180
Water resources 180
General conditions 180
Domestic supplies 180
Irrigation 181
Local supplies 181
Wynne 181
Parkin 182
Vanndale 182
Five miles east of Cherry Valley 183
Fairoaks 183
Wells for irrigation 183
Greene County 186
Physiography 186
Geology 187
Water resources 188
General conditions 188
Local supplies 188
Paragould 188
Rural supplies 189
Independence County 192
Physiography 192
Geology 192
Water resources 193
General conditions 193
Local supplies 193
Jackson County 194
Physiography 194
Geology 195
Water resources 196
General conditions 196
Local supplies 196
Jefferson County 197
Physiography 197
Geology 198

Digitized by Google

County descriptions—Continued.
Jefferson County—Continued. Page.
Water resources. . . . 198
Domestic supplies . . . 198
Wells for irrigation . . . 198
Lawrence County . . . 202
Physiography . . . 202
Geology . . . 202
Water resources . . . 203
General conditions . . . 203
Local supplies . . . 204
Walnut Ridge . . . 204
Alicia . . . 204
Black Rock . . . 204
Lynn . . . 204
Wells for irrigation . . . 205
Lee County . . . 208
Physiography . . . 208
Geology . . . 209
Water resources . . . 209
General conditions . . . 209
Local supplies . . . 210
Marianna . . . 210
Lagrange . . . 211
Wells for irrigation . . . 211
Lonoke County . . . 214
Physiography . . . 214
Geology . . . 214
Water resources . . . 215
General conditions . . . 215
Ordinary supplies . . . 215
Irrigation . . . 215
Local supplies . . . 216
Lonoke . . . 216
Holland . . . 216
Cabot . . . 217
Wells for irrigation . . . 218
Mississippi County . . . 224
Physiography . . . 224
Geology . . . 224
Water resources . . . 225
General conditions . . . 225
Local supplies . . . 225
Osceola . . . 225
Blytheville . . . 225
Luxora . . . 226
Burdette . . . 226
Wilson . . . 226
Ashport Bend, Mississippi River . . . 226
Monroe County . . . 229
Physiography . . . 229
Geology . . . 229

Digitized by Google

County descriptions—Continued.
Monroe County—Continued. Page.
Water resources. . . . 230
General conditions. . . . 230
Local supplies. . . . 230
Brinkley. . . . 230
Wells for irrigation. . . . 231
Phillips County. . . . 234
Physiography. . . . 234
Geology. . . . 235
Water resources. . . . 236
General conditions. . . . 236
Local supplies. . . . 236
Helena. . . . 236
Barton. . . . 239
Southland. . . . 239
Poinsett County. . . . 242
Physiography. . . . 242
Geology. . . . 243
Water resources. . . . 243
General conditions. . . . 243
Ordinary supplies. . . . 243
Irrigation. . . . 244
Local supplies. . . . 244
Harrisburg. . . . 244
Marked Tree. . . . 245
Weiner. . . . 246
Wells for irrigation. . . . 246
Prairie County. . . . 250
Physiography. . . . 250
Geology. . . . 250
Water resources. . . . 251
General conditions. . . . 251
Ordinary supplies. . . . 251
Irrigation. . . . 251
Local supplies. . . . 252
Hazen. . . . 252
Des Arc. . . . 252
Wells for irrigation. . . . 252
Pulaski County. . . . 256
Physiography. . . . 256
Geology. . . . 256
Water resources. . . . 257
General conditions. . . . 257
Local supplies. . . . 257
Little Rock. . . . 257
Argenta. . . . 258
Jacksonville. . . . 259
Randolph County. . . . 261
Physiography. . . . 261
Geology. . . . 261
Water resources. . . . 262

Digitized by Google

County descriptions—Continued. Page.
St. Francis County ... 262
Physiography ... 262
Geology ... 263
Water resources ... 264
General conditions ... 264
Ordinary supplies ... 264
Irrigation ... 265
Local supplies ... 265
Forrest City ... 265
Wells for irrigation ... 265
White County ... 270
Physiography ... 270
Geology ... 270
Water resources ... 271
General conditions ... 271
Local supplies ... 272
Bald Knob ... 272
Higginson ... 272
Woodruff County ... 275
Physiography ... 275
Geology ... 275
Water resources ... 276
General conditions ... 276
Local supplies ... 276
Augusta ... 276
Cotton Plant ... 276
Wells for irrigation ... 277
Chemical character of the waters of northeastern Arkansas, by R. B. Dole ... 281
Standards of classification ... 281
Mineral constituents of water ... 281
Water for boiler use ... 281
Formation of scale ... 281
Corrosion ... 282
Foaming ... 282
Remedies for boiler troubles ... 283
Boiler compounds ... 283
Numerical standards ... 284
Water for irrigation ... 287
Relation between applied water and soils ... 287
Numerical standards ... 287
Water for domestic use ... 289
Physical qualities ... 289
Bacteriological qualities ... 290
Chemical qualities ... 290
Purification of water ... 292
General requirements ... 292
Methods of purification ... 292
Slow sand filtration ... 293
Rapid sand filtration ... 294
Cold-water softening ... 295
Feed-water heating ... 296
Surface waters ... 298

Digitized by Google

Chemical character of the waters, by R. B. Dole—Continued. Page.
Ground waters ... 302
Chemical analyses ... 302
Field assays ... 304
Quality in relation to water-bearing stratum ... 305
Quaternary alluvium ... 305
Cretaceous and Tertiary formations ... 308
Quality in relation to geographic position ... 308
Quality in relation to depth ... 309
Economic value ... 309
Index ... 311

ILLUSTRATIONS.

Page.
PLATE I. *A*, Prairie phase of the Advance lowland, a quarter of a mile northeast of Obear, Craighead County; *B*, Low circular mound at Bald Knob ... 26
II. Preliminary geologic map of the Gulf Coastal Plain of eastern and northeastern Arkansas ... 30
III. Geologic cross sections ... 32
IV. Geologic cross sections ... 34
V. *A*, Pebbly limestone with interbedded layers of calcareous sand belonging to the Midway formation, on St. Louis, Iron Mountain & Southern Railway a quarter of a mile south of Grandglaise, Jackson County; *B*, Sands, clays, and lignites of the Wilcox formation on Bolivar Creek near its point of emergence from Crowleys Ridge, 3½ miles north of Harrisburg, Poinsett County ... 52
VI. *A*, Sands and clays of the Claiborne formation three-fourths of a mile southeast of Cherry Valley, Cross County; *B*, Leaf-bearing concretions of iron carbonate in clay of the Claiborne formation at the lower end of the bluff shown in Plate VI, *A* ... 68
VII. *A*, Fossiliferous clay of the Jackson formation overlain in ascending order by unfossiliferous sands and clays of this same formation, the Lafayette formation, and the loess, on Little Crow Creek 3 miles east of Forrest City, St. Francis County; *B*, Near view of the base of the bluff on Little Crow Creek shown in Plate VII, *A* ... 76
VIII. *A*, Gravel of the Lafayette formation exposed in the west slope of Crowleys Ridge near Colt, St. Francis County; *B*, Gravel of the Lafayette formation exposed in a pit of the St. Louis, Iron Mountain & Southern Railway 2 miles west of Newark, Independence County ... 88
IX. *A*, Loess exposed in a gully on the eastward-facing slope of Crowleys Ridge near Helena, Phillips County; *B*, Unconformable contact between the Lafayette formation and the loess in a gully near a small spring at the foot of Crowleys Ridge a quarter of a mile south of the Big Spring and 2½ miles north of Helena ... 102
X. *A*, "Old soil" zone in loess on southward-facing side of cut of St. Louis, Iron Mountain & Southern Railway 1½ miles east of Wynne, Cross County; *B*, Loess exposed in a cut of the Chicago, Rock Island & Pacific Railway through Crowleys Ridge a quarter of a mile east of Forrest City, St. Francis County ... 108
XI. Map of the ground-water resources of eastern and northeastern Arkansas ... 134

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Page.

FIGURE 1. Sketch to show the relations of formations exposed in a bluff on a small creek 3 miles east of Wynne, Cross County..... 71
2. Sketch to show the successive positions of oyster beds as deposition continued, as revealed in the base of the bluff on Little Crow Creek 3 miles east of Forrest City, St. Francis County..... 77
3. Section to illustrate artesian and nonartesian conditions in the Advance lowland west of Crowleys Ridge..... 142
4. Generalized section to explain the cause of artesian flows in the Mississippi lowland..... 143

INSERTS.

Page.

Chemical composition of water from wells in eastern and northeastern Arkansas. 302
Field assays of ground waters of eastern and northeastern Arkansas..... 304

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GEOLOGY AND GROUND WATERS OF NORTHEASTERN ARKANSAS.

By Lloyd William Stephenson and Albert Foster Crider.

INTRODUCTION.

PHYSIOGRAPHIC PROVINCES OF ARKANSAS.

Arkansas is divisible into two physiographic provinces. The area northwest of a line running from the northeastern corner of Randolph County southwestward through Powhatan, Searcy, and Little Rock, to near Arkadelphia, Clark County, and thence westward, is included in the division known as the Ozark province and embraces approximately 25,000 square miles. The rest of the State is included in the Gulf Coastal Plain, the area of which is approximately 27,500 square miles. More than half of the Gulf Coastal Plain falls within the physiographic division known as the Mississippi embayment, a broad arm which extends from the main plain up the valley of Mississippi River to the southern part of Illinois, a distance of approximately 250 miles. The Ozark province is separated from the Gulf Coastal Plain by an escarpment which in most places is well defined.

The Ozark province in this State is hilly to mountainous and lies 400 to 2,100 feet above sea level. North of Arkansas River the surface is a deeply dissected plateau, 500 to 1,500 feet above sea level, broken by one east-west ridge known as Boston Mountain, which rises to a maximum of about 2,000 feet above sea level. The part of the province south of Arkansas River is known as the Ouachita Mountains and consists of a series of ridges trending in a general east-west direction and rising 500 to 2,100 feet above sea level.

The Ozark province in Arkansas is drained chiefly by Spring, White, Arkansas, and Ouachita rivers, all of which flow in southeastward courses to or beyond its border.

The province is underlain by Paleozoic sedimentary rocks consisting of limestones, sandstones, and shales belonging to the Ordovician, Silurian, Devonian, and Carboniferous systems. In the plateau region north of Arkansas River these rocks lie nearly horizontal; in the region of Arkansas River valley, between Boston Mountain on the north and the Ouachita Mountains on the south, the strata are

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broadly folded; in the Ouachita Mountains south of Arkansas River the rocks are strongly folded into east-west synclines and anticlines.

In Arkansas the Gulf Coastal Plain ranges in elevation from 100 to 650 feet above sea level, and is divisible topographically into a series of interstream uplands in various stages of dissection, ranging in elevation from 200 to 650 feet above sea level, and a series of nearly level to gently rolling lowlands lying 100 to 300 feet above the same datum plane. A slight general slope southward characterizes both the uplands and the lowlands. The drainage of this part of the Gulf Coastal Plain reaches the Mississippi through numerous tributaries, the largest of which are St. Francis, White, Arkansas, Ouachita, and Red rivers.

The uplands are composed mainly of unconsolidated clays, loams, marls, sands, and gravels of Cretaceous and Tertiary age. The Cretaceous deposits outcrop in an east-west belt, 15 to 30 miles wide, lying south of the Ozark province and west of Ouachita River, both the Lower and Upper Cretaceous series being represented. Beds of Cretaceous age also lie buried beneath Tertiary strata in the vicinity of Little Rock and northeast of Little Rock in Lonoke and White counties, and Cretaceous strata come to the surface in the Grandglaise terrace in the vicinity of Newark, Independence County.

Except in the areas mentioned, the soils in the Gulf Coastal Plain uplands are immediately underlain by strata of Tertiary age belonging to the Midway, Wilcox, Claiborne, and Jackson formations of the Eocene, and the Lafayette formation of the Pliocene (?). Locally the Tertiary strata in the uplands are overlain and concealed by deposits of late Pleistocene age, principally consisting of loess, sands, and gravels. The loess occurs on Crowleys Ridge in the northeastern part of the State. The soils in the lowlands are immediately underlain by alluvial deposits which consist of silts, loams, clays, sands, and gravels of Pleistocene and Recent age, which rest unconformably upon Cretaceous and Tertiary strata.

ACKNOWLEDGMENTS.

The field investigations on which the report is largely based were made by the authors jointly during May and June, 1905, under the direction of M. L. Fuller, supervising geologist in charge of Coastal Plain investigations, and by the senior author under the direction of T. Wayland Vaughan, geologist in charge of Coastal Plain investigations, during October, 1910, and half of September, 1912.

The field studies have been supplemented by much information relating to the ground-water resources of the area, obtained by correspondence with municipal authorities, postmasters, and well owners. The authors desire to acknowledge their indebtedness to the follow-

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ing persons for important contributions to the hitherto unpublished scientific results presented:

Mr. T. Wayland Vaughan, who collected and identified the invertebrate fossils from Little Crow Creek, east of Forrest City.

Mr. E. W. Berry, who, in company with the senior author, collected fossil plants from several localities in Crowleys Ridge, identified the fossil plant species listed in the report, and determined the Wilcox and Claiborne age of plant-bearing beds in Crowleys Ridge north of St. Francis County.

Dr. Paul Bartsch, who identified the loess fossils from several localities on Crowleys Ridge in St. Francis and Phillips counties.

Mr. E. Wesley Shaw, who made petrographic studies of specimens of loess from various localities in the area, and who offered valuable suggestions regarding the geologic history of the late Tertiary and Quaternary deposits.

Grateful acknowledgments are also extended to the many citizens who furnished valuable information regarding the ground-water resources of the area, especially to Mr. E. G. Norton, of Brinkley, who contributed data relating to wells in Monroe, St. Francis, and other counties, and to Mr. W. H. Fuller, of Lonoke, who furnished an account of the early history of the rice industry.

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OWEN, DAVID DALE, First report of a geological reconnaissance of the northern counties of Arkansas, pp. 1–191, 10 pls. (esp. pp. 19–41), Little Rock.

Includes notes on the following counties: Greene (now in part Clay County), Poinsett (now in part Cross County), Jackson, Independence, and White (pp. 19–41). Owen correlates the unconsolidated deposits of Crowleys Ridge in northern Arkansas, including those of both Eocene and Pleistocene age, with the Quaternary; the hard Eocene quartzites he referred erroneously to the Potsdam sandstone (Cambrian).

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WILSON, E. H., Report on the results of borings at Memphis, Tenn., Helena, Ark., Arkansas City, Ark., Greenville, Miss., and Lake Providence, La., with data pertaining to similar work previously executed: U. S. Mississippi River Com. Progress Report, 47th Cong., 1st sess., S. Ex. Doc. No. 10, Appendix J and Ji, pp. 139–257.

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Contains references to the gravel and loess deposits capping Crowleys Ridge. The gravels they believe to be of pre-Pleistocene age and separated from the overlying loess by an erosion unconformity. In terms of the accepted classification of that time, the loess is correlated with the first glacial epoch. On the evidence of an apparent soil zone in the body of the loess, observed at Forrest City and elsewhere in the ridge, the loess is subdivided; the part below the soil zone is referred to the first episode of the first glacial epoch and the part above the soil zone to the second episode of the first glacial epoch. The alluvial filling of the Mississippi Valley is referred in time to the second glacial epoch.

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Includes a general description of the ridge and detailed descriptions of many geologic sections and other natural features. A map showing the geographic position of the ridge accompanies the report. St. Francis County is given special attention in a chapter entitled "Report on St. Francis County" (pp. 143–183), accompanied by a topographic and geologic map of a part of the county on a scale of 4 miles to the inch, with a contour interval of 10 feet. Supplementary to the report are descriptions of geologic sections on Arkansas River in White, Woodruff, Lonoke, and Prairie counties, and at Memphis, Tenn.

Call recognizes the Tertiary age of the strata composing the core of Crowleys Ridge, but he does not differentiate the Wilcox, Claiborne, and Jackson formations, which outcrop in succession from the northern to the southern end of the ridge. Although he recognizes the fact that the main body of the gravels is younger than the underlying sands and clays, he does not clearly distinguish between the Eocene strata and the overlying Lafayette formation. The loess capping the ridge he correlates correctly with the Pleistocene.

BRANNER, J. C. In the preface to vol. 2 of the Arkansas Geol. Survey Ann. Rept. for 1889, pp. xi–xvi.

Branner gives a brief account of the origin of Crowleys Ridge and describes the depression which brought into existence the conditions necessary to the deposition of the Tertiary (Eocene) deposits of the embayment. He recognizes that at a later time the Mississippi River followed a course west of Crowleys Ridge and that through its agency the great lowland between the ridge and the Ozark province was eroded out and partially refilled; he states that Ohio River, following a course southward east of the ridge, was accomplishing similar results in the area now known as the Mississippi lowland; the junction of the two streams was somewhere south of Helena. Crowleys Ridge is correctly interpreted to be an erosion remnant which separates these two great valleys.

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Describes the main drainage events of the embayment area in southeastern Missouri and many of the lesser phenomena. Marbut states that Mississippi River in the early part of the second glacial epoch flowed from Cape Girardeau southwestward, west of Benton Ridge and Crowleys Ridge; Ohio River flowed southward, east of these ridges, and joined the Mississippi south of the southern extremity of Crowleys Ridge in Arkansas. The lowland produced by the erosion of Mississippi River he designated the Advance lowland, from the village of Advance, situated upon the lowland in Stoddard County, Mo.

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After the main features of the Advance lowland had been fashioned by Mississippi River the stream was captured by Ohio River; first, at the point now marked by the gap separating the northern extremity of Crowleys Ridge from the southern extremity of Benton Ridge; and, second, at the point now occupied by the Mississippi between Grays Point and Commerce, Scott County, Mo. The lowland produced by the erosion of Ohio River and by the combined erosion of the Ohio and Mississippi, after the capture of the latter stream, was designated by Marbut the "Cairo lowland," which he subdivided into the Charleston lowland, Sikeston Ridge, and the Morehouse lowland.

The author discusses at considerable length the manner in which these great feats were accomplished, and also the details of many minor incidents connected with the major processes. The paper is accompanied by a topographic map on a scale of approximately 3 miles to the inch with a 20-foot contour interval (Plate VI) and a black and white geologic map on the same base (Plate VII).

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Includes a compilation of the known facts regarding the phenomena accompanying and resulting from the earthquake, gathered from many sources, and the results of several season's work by the author in the area. From the available data he makes deductions regarding the origin and cause of the earth movement, and concludes that the ultimate cause was a disturbance in the consolidated basement rocks underlying the deposits of the Gulf Coastal Plain. A map which shows the distribution of the various recognizable effects of the earthquake, such as sunk lands, areas of fissuring, areas of sand blows, and areas of landslides, accompanies the paper.

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Discusses the age of the igneous rocks of southwest Arkansas, which he shows were intruded during the period represented by the uncon-

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PHYSIOGRAPHY.

CLASSIFICATION OF FEATURES.

The area covered in this report is included within the broad northward-extending arm of the Gulf Coastal Plain known as the Mississippi embayment and embraces approximately 13,250 square miles, extending from Mississippi River westward to the border of the Ozark province and from the Missouri State boundary southward to Arkansas River. The embayment may be subdivided into uplands and lowlands.

Probably more than nine-tenths of the area treated in this report presents a lowland type of topography and is embraced within the two physiographic divisions of the Mississippi embayment designated the Advance lowland and the Mississippi lowland.

The Ozark province, a rugged, hilly area lying 400 to 1,500 feet above sea level, borders the Gulf Coastal Plain on the northwest. This higher land is separated from the Coastal Plain by an escarpment, which at most places is sharply defined.

COASTAL PLAIN UPLANDS.

Southwest of Arkansas River.—Between Arkansas and Ouachita rivers is an extensive, partly dissected upland, the elevation of which is 200 to 500 feet above sea level. This upland is terminated on the northeast by a more or less clearly defined escarpment, which overlooks the Advance lowland and marks its southwest boundary. The difference in elevation between the upland and the Advance lowland is 150 to 250 feet.

Crowleys Ridge.—Crowleys Ridge is a belt of upland which, with certain important interruptions, extends from Stoddard County, Mo., where the maximum width is 18 miles, southwestward through Clay County, Ark., to Craighead County, Ark., and thence southward to Helena, Phillips County. In Phillips County the crest of the ridge is about 400 feet above sea level; the elevation gradually increases northward to 500 feet above sea level in Clay County, and to a maximum of 600 feet in Stoddard County, Mo. The elevation of

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the crest above the lowlands to the east and west ranges from 100 to 260 feet, the greatest difference being in Stoddard County, Mo.

In Arkansas the ridge varies in width from one-half mile to 12 miles; the broadest part of the belt is in Craighead and Greene counties, where the width is 8 to 12 miles, and the narrowest part is near Dee, in Craighead County, where there is a low gap, through which the Helena branch of the St. Louis, Iron Mountain & Southern Railway passes. The ridge has been completely cut at three places; one gap, in Stoddard County, Mo., is occupied by Castor River; another, on the border between Clay County, Ark., and New Madrid County, Mo., serves as the passageway of St. Francis River from the Advance lowland to the Mississippi lowland; the third, in Lee County, Ark., is several miles wide and is occupied by L'Anguille River.

The surface of the ridge is dissected by numerous small perennial and intermittent streams, most of which flow either to the east or to the west at right angles to the trend of the ridge; at many places the topography is rugged, but elsewhere erosion has passed beyond the stage of maturity, and the hills present smoothly rounded, gentle slopes. Several of the larger streams flow through relatively broad, shallow valleys.

The ridge is sharply separated from the adjoining lowlands by escarpments of varying degrees of steepness. At many places in Cross, St. Francis, Lee, and Phillips counties the east-facing slope is an abrupt bluff; in Craighead, Greene, and Clay counties the west-facing slope is relatively steep. The broader valleys and the more gently rounded hills have been cleared for cultivation, but the greater part of the area is covered with timber.

Benton Ridge (in Missouri).—Benton Ridge, in Scott County, is a northeastward extension of Crowleys Ridge, but is separated from it by a gap 10 miles wide; Benton Ridge terminates near Commerce just west of Mississippi River.

Grandglaise terrace.—Bordering the Ozark province and extending with certain interruptions from the northeastern part of White County through Independence County to the southern part of Lawrence County, is a narrow, more or less clearly defined bench, here designated the Grandglaise terrace, which lies 250 to 325 or 350 feet above sea level, and from 40 to 100 or 125 feet above the Advance lowland on the east. This terrace has been dissected by numerous streams crossing it from the Ozark province to the Advance lowland, chief of which is White River, and in places, particularly in Jackson County, small streams running parallel with the terrace along its western margin partly separate it from the Ozark hills to the west, leaving the terrace represented only by a ridge.

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The term "Grandglaise area" was first used by Purdue[1] for the portion of the terrace between "Coffeyville and Bradford," in Lonoke and White counties. Since the terrace north of White River in Independence and Lawrence counties is the northward continuation of the terrace at Grandglaise, it is appropriate to extend the application of the term to that area.

Chinquapin Ridge.—An elevated tract in Lonoke County extending from the border of the Ozark province in the vicinity of Austin and Cabot to the eastward and southward for several miles has been locally termed Chinquapin Ridge; Purdue[2] called it the "sandhill" area. The exact limits of this tract have not been determined, but its north-south extent is believed to be about 12 miles, and its east-west extent is approximately 6 miles. The area presents a series of rolling hills rising to a maximum of 375 or 400 feet above sea level, and 125 to 150 feet above the level of the adjoining Advance lowland. The soils consist mainly of reddish, ferruginous sands derived from sandy strata probably of Eocene age which compose the body of the hills. The southwestern end of the ridge is expressed on the Little Rock topographic map by the 300-foot contour, which appears on the map east and north of Bayou Two Prairie and south of Cabot. A small elevated tract west of Bayou Two Prairie, in the vicinity of Jacksonville, expressed on the Little Rock map by the 300-foot contour, may be considered an isolated remnant of this ridge, as may also a similar small elevated tract north of Cypress Bayou and southwest of Beebe, in the southern part of White County.

Jones Ridge.—In addition to the uplands already described, there is one minor elevation in Arkansas, known as Jones Ridge, which deserves brief mention. This ridge is in the northeastern part of Greene County, between Cache River and the St. Louis, Iron Mountain & Southern Railway, where the nearly level surface of the lowland is broken by a northeast-southwest swell, 3 or 4 miles long, one-quarter to one-half mile wide, and 30 to 40 feet high. The probable age and relations of the ridge are discussed on page 111.

Chickasaw Bluffs (in Kentucky, Tennessee, and Mississippi).—The Mississippi lowland is bordered on the east in Kentucky, Tennessee, and Mississippi by an area lying about 400 feet above sea level or 100 to 150 feet above the level of the lowland. This higher land is separated from the lowland to the west by a line of bluffs, known as Chickasaw Bluffs, which extends from northeast to southwest, approximately parallel to the general course of the Mississippi River; north of Memphis the bluffs are nowhere more than 15 miles

[1] Water resources of the contact region between the Paleozoic and Mississippi Embayment deposits in northern Arkansas: U. S. Geol. Survey Water-Supply Paper 145, p. 94, 1905.

[2] Idem, p. 93.

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from the Mississippi River, but south of Memphis they form the eastern boundary of Yazoo bottom, which lies east of the river and has a maximum width of 65 miles.

COASTAL PLAIN LOWLANDS.

ADVANCE LOWLAND.

The name "Advance lowland" is derived from the village of Advance, in the northern part of Stoddard County, Mo., and was first used by Marbut[1] in 1902 for a belt of lowland extending from the Mississippi River at Cape Girardeau, Mo., southwestward to Mingo, in the western part of Stoddard County, and thence southward into Arkansas.

From Cape Girardeau to Mingo the Advance lowland is 2½ to 6 miles wide; southward from Mingo it broadens out, and from the Arkansas State line to the latitude of Jonesboro, in Craighead County, is 25 to 30 miles wide; from Craighead County southward it broadens, reaching a maximum of about 90 miles in the latitude of Little Rock, which width it maintains approximately to its junction with the Mississippi lowland.

The Advance lowland is limited on the east by Crowleys Ridge, on the northwest by the Ozark province, on the southwest by the upland south of the Arkansas River, and on the southeast by the Mississippi lowland. The Advance lowland merges into the Mississippi lowland along a line which runs from Helena in an approximate southwestward direction to the southern part of Arkansas County.

The surface of the Advance lowland is, in general, a nearly level or gently rolling plain, which stands about 342 feet above sea level at Cape Girardeau, Mo., whence it slopes gradually southwestward and southward at an average rate of about two-thirds of a foot a mile to about 150 feet above sea level at its southern extremity in Arkansas.

Although now crossed by numerous streams the main topographic features of the Advance lowland are obviously the product of one great agent; Marbut[2] has shown that the lowland in Missouri is an abandoned valley of Mississippi River, and the conclusion seems justified that this great stream once meandered in the area included in this division in Arkansas.

At the present time the Advance lowland in Arkansas is drained chiefly by Arkansas, White, and L'Anguille rivers and their tribu-

[1] Marbut, C. F., The evolution of the northern part of the lowlands of southeastern Missouri: Missouri Univ. Studies, vol. 1, No. 3, 63 pp. (esp. p. 4), 7 pls., 1902.
[2] Idem, pp. 47–63.

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taries. Arkansas River enters the lowland at Little Rock, flows southeastward, and joins Mississippi River in Desha County; its principal tributary is Bayou Meto, and there is a network of bayous in Arkansas, Jefferson, Lonoke, and Pulaski counties.

White River enters the lowland at Batesville, Independence County, flows in a general southward course, and enters Mississippi River by means of a network of distributaries through a part of which the waters of Arkansas River also flow. The principal western tributaries of White River, from north to south, are Little Red River, Bayou Des Arc, Wattensas Bayou, and Big Lagrue Bayou. Black River enters Arkansas in Clay County, flows southwestward near the western border of the lowland, and joins White River near Newport, Jackson County. Cache River rises in the northern part of Clay County, flows southwestward near the center of the lowland, and joins White River near Clarendon. Bayou De Vue, a tributary of Cache River, parallels the latter stream about 8 or 10 miles to the eastward, from Craighead County southwestward to Monroe County. Big Creek flows from the western part of St. Francis County southward to the western part of Phillips County, where it joins White River.

The only other important stream in the area is L'Anguille River, which rises in the northern part of Poinsett County, flows southward a short distance west of Crowleys Ridge, turns southeastward, and leaves the Advance lowland through a gap at Crowleys Ridge in Lee County.

The streams of the Advance lowland flow through broad, shallow valleys which are a few feet to a maximum of 35 or 40 feet below the level of the interstream areas. All the larger streams flow in courses approximately parallel to the linear direction of the main lowland, but in detail the channels are sinuous and the currents are sluggish.

The bottom lands are characterized by numerous swamps, bayous, lakes, and abandoned stream channels, which at many places are separated by low ridges rising only a few feet above the level of the depressions. The flood plain soils are fertile and support a vigorous growth of timber; where well situated as regards drainage they can be made to yield large crops of cotton, corn, and other products. Many of the low ridges are cultivated.

Between the flood plains of the streams are gently undulating plains, underlain except at certain places by silty loams and clays. The soils vary from dark, fertile, sandy or nonsandy loams, to light-gray, silty loams and clays which are not well suited to many of the common crops; in most places the soils rest on compact clay subsoils which are almost impervious to water. At many places the clay soils are ferruginous and are filled with numerous small concretions of iron oxide; soils of this character are locally termed "buckshot lands."

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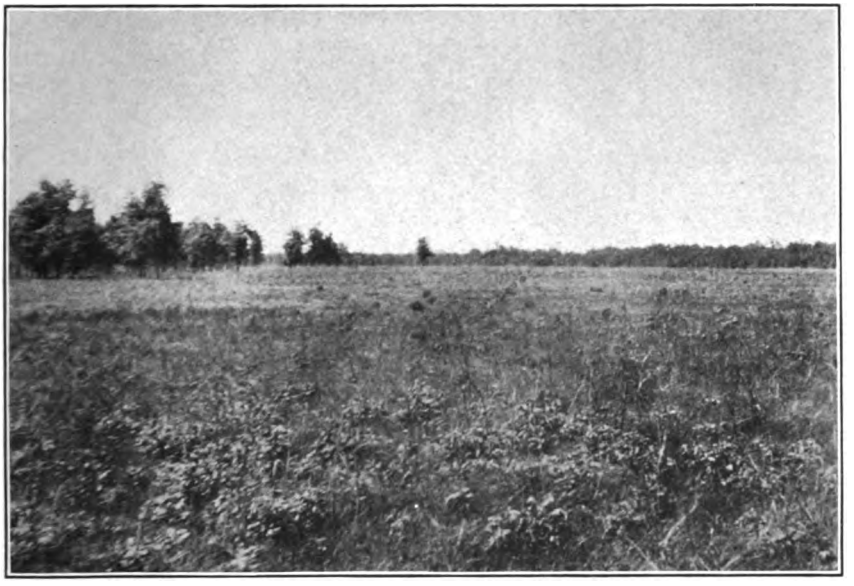
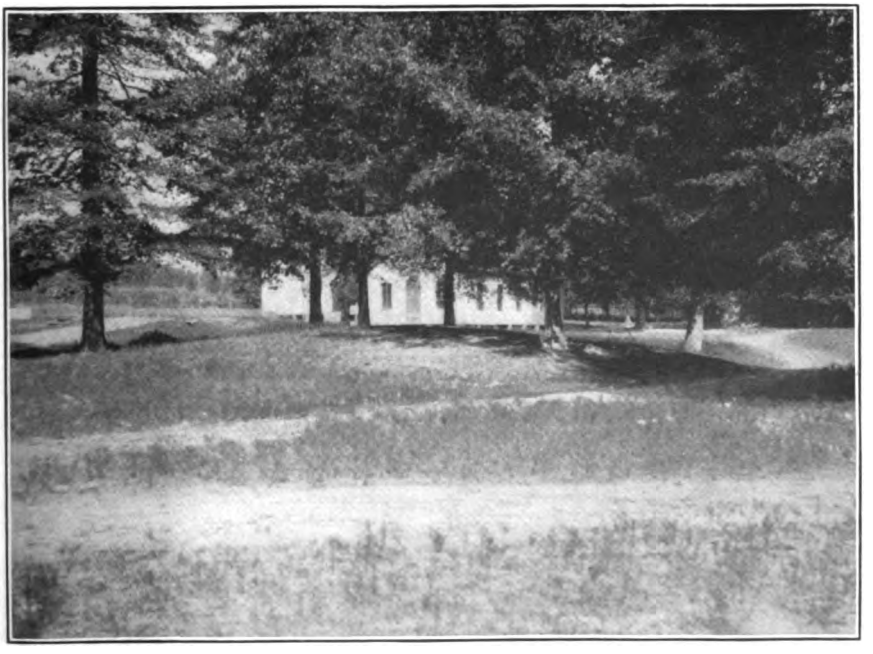


A. PRAIRIE PHASE OF THE ADVANCE LOWLAND, A QUARTER OF A MILE NORTHEAST OF OBEAR, CRAIGHEAD COUNTY.



B. LOW CIRCULAR MOUND AT BALD KNOB.

A typical example of the small mounds common in certain parts of the Coastal Plain of Arkansas, Louisiana, and eastern Texas.

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A considerable part of the interstream areas consists of irregularly distributed small and large tracts of gently undulating grass-covered prairie lands. Grand Prairie is an irregular but nearly continuous tract of prairie, extending from northwest of Lonoke, in Lonoke County, southeastward through Prairie County nearly to the southern extremity of Arkansas County. The prairie is broken by numerous slightly depressed patches and strips of timbered land, and by the shallow valleys of numerous small creeks and bayous. Prairie Longue is a similar but smaller tract in Lonoke County south of Bayou Two Prairie. Numerous patches of prairie land lie between Bayou De Vue and L'Anguille River in Lee, Monroe, St. Francis, Woodruff, Cross, Poinsett, and Craighead counties. (See Pl. I, *A*.) The prairie soils are best suited to grazing, the raising of hay, and rice culture.

Surrounding and separating or partly separating the patches and tracts of prairie lands are slightly depressed lands supporting a growth of such trees as post and other small varieties of oak, sassafras, persimmon, and sumac.

In places gently undulating areas, with soils that appear to be essentially like the prairie soils, are timber covered except where artificially cleared. Tracts of this kind are found in many of the counties, but particularly in those lying directly east of the border of the Ozark province.

West of and bordering Crowleys Ridge is a belt of heavily timbered land, the soils of which are more fertile than most of the soils of the interstream areas elsewhere in the Advance lowland; this belt owes its fertility to wash materials from Crowleys Ridge.

At many places in the Advance lowland, but particularly in Clay, Randolph, and Lawrence counties in the north, and in the counties bordering the Ozark province, there are tracts of rolling timbered land composed of numerous low ridges of sand or sandy loam, which in general trend parallel to the stream courses. Some of these ridges appear to be a part of the alluvial deposits of the present streams, but many of them rise above extreme high-water level, are probably of Pleistocene age, and may properly be classed as interstream lands.

In Monroe and Phillips counties, west of the southern extremity of Crowleys Ridge, is a ridge 10 to 30 feet high and 2 to 3 miles wide, known as Hickory Ridge, which extends from near Blackston, in the former county, southeastward to several miles beyond Marvell in the latter county. There are several similar ridges between Hickory Ridge and the southern nose of Crowleys Ridge. Along the western side of Crowleys Ridge, in Phillips County, is a well-defined terrace, 1 to 3 miles wide and 30 or 40 feet higher than the bottom lands of Caney Creek, which lies immediately to the west; the terrace is

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separated from the ridge on the east and the bottom lands on th west by abrupt escarpments, and probably corresponds in elevatio to the ridges just described. The series of ridges and the terrace hav probably been produced by erosion where the streams of the Advanc lowland pass down to the Mississippi lowland, which lies 30 or 4 feet lower.

MISSISSIPPI LOWLAND.

The Mississippi lowland in Arkansas includes all the area east o Crowleys Ridge and a belt 5 to 20 miles wide bordering Mississipp River on the west south of the southern extremity of Crowley Ridge. In Missouri this lowland includes the area southeast an south of Crowleys Ridge and south of Benton Ridge. The easter boundary of the lowland in Kentucky, Tennessee, and Mississippi i the Chickasaw Bluffs.

The Mississippi lowland is a gently undulating plain, slopin southward at a rate of about three-fourths of a foot per mile fro an elevation of about 340 feet above sea level at the northern en of the Mississippi embayment region near Commerce, Scott County Mo., to about 105 feet at the southern boundary of Arkansas.

Mississippi River, which forms the eastern boundary of the State eventually receives all the drainage of the Mississippi lowland. I Arkansas and Missouri the surface immediately west of Mississipp River in any given cross section of the valley is the highest part o the lowland, and there is a slight gentle slope to the west. As a result of this condition the surface waters flow westward, eventuall reaching the Mississippi through several tributaries that parallel the main stream for long distances.

St. Francis River enters the lowland at the northeastern corner of Clay County and flows in a general southerly course near the western border of the lowland to a point 8 or 10 miles north of the southern extremity of Crowleys Ridge, near Helena, where it joins Mississippi River. Little River, which enters the lowland between Benton Ridge and the northern extremity of Crowleys Ridge in Missouri, flows southward and joins St. Francis River in Poinsett County, Ark.

Much of the lowland in Missouri and Arkansas presents a network of lakes, bayous, and abandoned stream channels, separated by areas of swamp land and by low ridges of sand and sandy loam. Nearly all these bodies of water are connected with the drainage systems of Little and St. Francis rivers. Much of the area is subject to overflow from Mississippi and St. Francis rivers.

A large area in the western part of the lowland, embracing parts of New Madrid, Dunklin, and Pemiscot counties, Mo., and Clay, Greene, Craighead, Poinsett, and Mississippi counties, Ark., is known

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as the St. Francis Sunk Lands. However, recent investigations of the Land Office and the United States Geological Survey have shown either the much smaller size or the nonexistence of many of the large lakes shown on the maps. The bearing of these facts, which were received too late for incorporation in the maps accompanying this report, on the claim that large tracts in this area sank during the time of the New Madrid earthquake, in 1811 and 1812,[1] has not been determined.

The depressions of the lowland are everywhere separated by low, rolling ridges, most of which are of relatively small extent and rise only a few feet above the level of the depressed areas. Two such areas, however, are of sufficient extent to deserve mention. Sikeston Ridge, or Big Prairie, is an elevated tract rising about 20 feet above the surrounding lowland, 2 to 4 miles wide, and extending from south of Lake St. John, Scott County, Mo., southward to New Madrid, in New Madrid County.

Another low ridge, resembling Sikeston Ridge, extends, with several interruptions, from the southern part of Stoddard County, Mo., a little west of south in a slightly sinuous course through Dunklin County, Mo., into the northern part of Mississippi County, Ark.; from north to south the different parts of this ridge are known, respectively, as Rosebriar Prairie, West Prairie, Grand Prairie, and Big Lake Highlands.

A belt of land, nowhere more than 5 or 6 miles wide, which borders Crowleys Ridge on the east from Clay County southward to the southern part of Craighead County, is a few feet higher than the main lowland to the east, and is underlain by "buckshot" clay soil similar to some of the prairie soils west of Crowleys Ridge, and may be of the same age (Pleistocene). This area is partly covered with materials washed from Crowleys Ridge.

Throughout the greater part of the Mississippi lowland the surface is underlain by dark, fertile loams, sandy loams, and sands, which support a vigorous growth of timber.

In a large area, including parts of New Madrid, Dunklin, and Pemiscot counties, Mo., and Clay, Greene, Craighead, Poinsett, and Mississippi counties, Ark., the ridges of sandy loam separating the depressions are dotted with so-called sand blows, which are low circular or irregular patches of clean white sand believed to have been extruded from underground sources during the time of the New Madrid earthquake in 1811 and 1812.[2] The sand blows contain but little vegetable mold and are poorly productive.

[1] Fuller, M. L., The New Madrid earthquake: U. S. Geol. Survey Bull. 494, pp. 64–75, 1912.

[2] Idem, pp. 79–83.

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SMALL MOUNDS.

Low circular mounds, 20 to 100 feet in diameter and 1 to 4 high (see Pl. I, *B*), constitute a curious but minor topographic ture in certain parts of Arkansas and in places are numerous. lar mounds of like origin in adjoining States have been describ Veatch.[1]

The writers have observed these mounds in Pulaski, Jeffe Lonoke, White, Jackson, Independence, Lawrence, and Clay cou The materials composing some of the mounds are slightly co and lighter in color than the surrounding soils, but others appe be essentially like these soils in structure, composition, and c The mounds are not restricted to any particular type of topogr except that they were not observed on the flood plains of the pr streams. They occur on the interstream areas of the Advance land, on the Coastal Plain uplands along the western border o embayment, and on the slopes of the Paleozoic hills bordering Coastal Plain.

No theory thus far proposed seems satisfactorily to explain origin of the mounds. Veatch discussed the several hypotheses have been advanced to account for them (pp. 56–59 of the re cited) and regarded the spring and gas-vent theories, the theory, and the ant-hill theory as most deserving consideration. occurrence of the mounds in various topographic positions and geologic formations of all ages from Cretaceous to Pleistocene w seem to render the spring and gas-vent theories untenable.

Their uniformly circular shape is believed to preclude the sibility of their having been formed by wind. The same objec seems to apply to the theory of their formation by ants or burrow animals; besides, no such mounds are known to be in process of mation at the present time, and if formed by either of these agen the species responsible for their construction, whether insect rodent, has either migrated from the region or become extinct. theory that they are of human origin is one that appeals strongl the imagination, chiefly because of the remarkable symmetry of mounds and their distribution. Their vast numbers in certain ar however, would seem to preclude the possibility of their having b formed by man. For instance, along the line of the Texas & Pa Railway between Texarkana and Annona, Tex., a distance of m than 50 miles, the mounds occur in astonishing numbers. Many fi are almost completely covered with them, the outer edges of many

[1] Veatch, A. C., Geology and underground water resources of northern Louisiana southern Arkansas: U. S. Geol. Survey Prof. Paper 46, pp. 55–59, 1906.

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the mounds even being in contact with one another. In order to account for their construction by human beings it would seem necessary to postulate a prehistoric race numbering many millions.

GEOLOGY.

GENERAL COMPOSITION AND STRUCTURE OF THE AREA.

The Mississippi embayment is a broad arm of the Gulf Coastal Plain extending about 250 miles up the valley of Mississippi River to the southern extremity of Illinois. The area is surrounded on the west, north, and east by a territory in which are consolidated sedimentary rocks of Paleozoic age. Structurally the embayment is a down-warped trough of Paleozoic rocks filled to the level of the present surface with deposits, mostly unconsolidated, ranging in age from Cretaceous to Recent. The axis of the trough trends slightly west of south and the maximum depth, though not determined, probably exceeds 3,000 feet; the depth at Memphis has been shown by well borings to be more than 2,500 feet.

The areal distribution of the geologic formations which outcrop within the area treated in this report is indicated on the geologic map, Plate II. An idea of the structure of the Mississippi embayment may be had by referring to the geologic sections given in Plates III and IV. A–B–C–D (Pl. III) is a section along the linear direction of Crowleys Ridge from the northern extremity of the ridge in Stoddard County, Mo., to the southern extremity of the ridge in Phillips County, Ark.; E–F (Pl. III) is a section across the embayment from the vicinity of Supply, Randolph County, Ark., to a point 12 miles east of Paris, Henry County, Tenn.; G–H (Pl. IV) is a section across the embayment from Grandglaise, Jackson County, Ark., to a point 10 miles south of Decaturville, Decatur County, Tenn.; I–J (Pl. IV) is a section extending partly across the embayment from Little Rock, Pulaski County, Ark., to near Helena, Phillips County, Ark. In these sections the elevation of the upper surface of the Eocene is in most places represented too low, owing to the necessary exaggeration of the thickness of the Lafayette formation.

Deposits of Cretaceous age occupy the bottom of the trough and probably reach a maximum thickness of 2,000 feet or more. They outcrop in a relatively narrow belt along the eastern limb of the trough in Alabama, Mississippi, Tennessee, and southern Illinois, and along the western limit of the trough in the vicinity of Newark, Independence County, Ark.; they are also present at a relatively shallow depth along the border of the Ozark province from Little Rock, Pulaski County, northeastward to Beebe, White County.

The Cretaceous deposits are overlain by Eocene deposits, including in ascending order the Midway, Wilcox, Claiborne, and Jackson for-

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mations, 1,000 feet or more in aggregate thickness. These forma
outcrop east of Mississippi River in Mississippi, Tennessee, Kentu
and southern Illinois; they form the core of Crowleys Ridg
Arkansas; they outcrop in the Coastal Plain uplands of south-ce
Arkansas, and in small areas along the western margin of the em
ment from Little Rock northeastward to the southern part of I
pendence County. In the broad belt of outcrop east of Missis
River the Eocene deposits are partly overlain by gravels and
of the Lafayette formation (Pliocene?) and the
partly overlain by deposits of loess (Pleistocene). The same
cession of surficial deposits occurs above the Eocene in Crow
Ridge. On the crests of the Paleozoic hills bordering the em
ment on the west and in places capping the Grandglaise terrace
scattered deposits of gravel, sand, and argillaceous loam, which p
ably represent, respectively, the Lafayette formation and the loess

The Cretaceous and Eocene deposits, the overlying Lafayette
mation, and the loess have been partly removed by the erosive act
of Mississippi and Ohio rivers to depths of 100 to 225 feet below
present surface of the lowlands, and the valleys have been par
refilled by deposits brought in by the same streams. In this manne
the Advance and Mississippi lowlands which cover the greater pa
of the area under consideration have been formed.

PALEOZOIC ROCKS.

Outcropping Paleozoic rocks.—The area treated in this report is bordered on the northwest by the Ozark province. In the contact region between the Gulf Coastal Plain and the Ozark province the rocks composing the latter consist of Paleozoic limestones, sandstones, and shales, representing the Ordovician, Silurian, and Devonian systems, which outcrop from Independence County northward to the State line, and the Carboniferous system, which outcrop from Independence County southward to Pulaski County.

The pre-Carboniferous rocks of Independence, Lawrence, and Randolph counties, which are chiefly magnesian limestones of the Ordovician system and subordinately limestones of Silurian and sandstones and shales of Devonian age, lie nearly horizontal or are only gently folded. The Carboniferous rocks of Independence, Jackson, White, Lonoke, and Pulaski counties, which include representatives of both the Mississippian and Pennsylvanian series, consist mainly of cherts, shales, and sandstones, with, however, a subordinate amount of limetones; these rocks vary in position from nearly horizontal to strongly folded.

From Little Rock northeastward to Missouri the Paleozoic hills immediately west of the Gulf Coastal Plain rise 400 to 500 feet or

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mations, 1,000 feet or more in aggregate thickness. These form outcrop east of Mississippi River in Mississippi, Tennessee, Ken and southern Illinois; they form the core of Crowleys Ri Arkansas; they outcrop in the Coastal Plain uplands of south-c Arkansas, and in small areas along the western margin of the e ment from Little Rock northeastward to the southern part of pendence County. In the broad belt of outcrop east of Miss River the Eocene deposits are partly overlain by gravels and of the Lafayette formation (Pliocene?) and the partly overlain by deposits of loess (Pleistocene). The same cession of surficial deposits occurs above the Eocene in Cro Ridge. On the crests of the Paleozoic hills bordering the e ment on the west and in places capping the Grandglaise terra scattered deposits of gravel, sand, and argillaceous loam, which ably represent, respectively, the Lafayette formation and the loe

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From Little Rock northeastward to Missouri the Paleozoic hills immediately west of the Gulf Coastal Plain rise 400 to 500 feet or

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Jonesboro, Ark.

Lagrange formation

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more above sea level, or 100 to 200 feet or more above the level of the Advance lowland to the east. The boundary is marked by a relatively abrupt escarpment which is believed to be a sea cliff formed along an early Eocene shore line.

Buried Paleozoic rocks.—The Paleozoic rocks are separated from the deposits of the Coastal Plain by a steep eastward-sloping nonconformable contact, which is the continuation beneath the surface of the ancient erosion escarpment that separates the Coastal Plain from the Ozark province. The contact maintains its relatively steep position to only a small depth, probably 20 to 50 feet, beyond which it flattens out and extends eastward beneath the deposits of the Coastal Plain at a slight dip, probably nowhere exceeding 75 feet to the mile. The buried Paleozoic rocks have been reached in numerous wells near the western margin of the Gulf Coastal Plain at depths ranging from 20 to 60 feet.

Little is known concerning the depth to the Paleozoic basement rocks in the Mississippi embayment except in close proximity to its outside rim. A few deep wells, however, have thrown some light on the subject.

A well at Newport, Jackson County, is believed to have entered the Paleozoic rocks at a depth of 655 feet.

A well at Stuttgart, Arkansas County, 40 miles southeast of the Paleozoic border, stopped on solid rock at a depth of 1,200 feet; the available data are insufficient to determine whether the rock was an indurated layer in the deposits of the Coastal Plain or the Paleozoic basement rocks.

A 1,265-foot well at Jonesboro, Craighead County, 30 miles from the Paleozoic border, did not reach the basement rocks.

A 960-foot well at Campbell,[1] Dunklin County, Mo., 24 miles from the Paleozoic border, also failed to reach the basement rocks.

A 960-foot well at Paducah, Ky., encountered Paleozoic limestone at a depth of 300 feet.

Two wells at Morehouse,[2] New Madrid County, Mo., 16 miles from the nearest outcrop of Paleozoic rocks, struck Cambrian limestone at depths of 690 and 696 feet, respectively.

A 2,007-foot well at Marked Tree, Poinsett County, Ark., 44 miles southeast of the Paleozoic border, did not reach the basement rocks.

A well near Memphis, Tenn., near the center of the Mississippi Embayment and about 145 miles south of the head of the embayment, was drilled to a depth of 2,500+ feet and did not reach the basement rocks.

[1] Shepard, E. M., Underground waters of Missouri: U. S. Geol. Survey Water-Supply Paper 195, pp. 175, 176, 1907.

[2] Idem, p. 175.

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MESOZOIC AND CENOZOIC FORMATIONS.

Generalized section.

A generalized section of the Mesozoic and Cenozoic form
the Coastal Plain of eastern and northeastern Arkansas is giv
following table:

*Generalized section of the Mesozoic and Cenozoic rocks of northea
Arkansas.*

System.	Series.	Formation.	Characteristics.
Quaternary.	Recent.		Alluvium; water-bearing.
	Pleistocene.		Alluvium; yields large quantities of water.
			Loess; not an important water-bearer.
		Unconformity	
	Pliocene (?).	Lafayette formation.	Gravels and sands; water-bearing in part.
		Unconformity	
Tertiary.	Eocene.	Jackson formation.	Sands, clays, and marls; water-bearing in part.
		Claiborne formation.	Sands, clays, lignites, and marls; water-bearing.
		Unconformity (?)	
		Wilcox formation.	Sands, clays, and lignites; water-bearing.
		Midway formation.	Limestones, sands, and marls; probably water-bearing in buried extension.
		Unconformity	
Cretaceous.	Upper Cretaceous.	Nacatoch sand (?).	Glauconitic sands, clays, and marls; probably water-bearing in buried extension.
		Unconformity	
(Paleozoic rocks undifferentiated.)			

[a] Maximum observed thickness.

Cretaceous system.

IGNEOUS INTRUSIONS OF LATE LOWER CRETACEOUS OR EARLY U
CRETACEOUS AGE.

Igneous intrusive rocks occur in one small tract in the area c
by the geologic map (Pl. II) accompanying this report. Thi
is in Pulaski County, a few miles south of Little Rock, and is k
as the Fourche Mountain region. The igneous rocks cons
Pulaskite (blue granite), elæolite syenite (gray granite), and s
other related varieties of rock. Associated with the igneous
and with the adjacent Tertiary sediments are important depos
bauxite, the chief ore of aluminum.

Williams[1] regarded the age of these rocks as late Cretace
early Tertiary.

[1] Williams, J. F., The igneous rocks of Arkansas: Arkansas Geol. Survey Ann. R
1890, vol. 2, pp. 5, 123, 1891.

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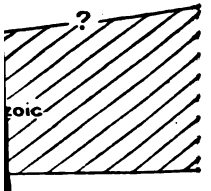

ormation

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Miser[1] has recently shown that the peridotites of southwest Arkansas, which are believed to be of approximately the same age as the igneous rocks near Little Rock, cut the Trinity formation (Lower Cretaceous), and that pebbles of several kinds of the igneous rocks of the region are included in the basal gravels of the Bingen sand (basal Upper Cretaceous). The Trinity and Bingen formations are separated by an unconformity and the intrusions must have occurred during the interval which it represents. In a more recent unpublished statement Miser expresses the opinion that the time of the intrusions was late Lower Cretaceous or early Upper Cretaceous, and they may have accompanied the downwarping that produced the transgression of the Upper Cretaceous sea in the Mississippi embayment.

UPPER CRETACEOUS SERIES.

CHARACTER AND DISTRIBUTION.

Strata of Upper Cretaceous age outcrop in a narrow area along the western border of the Mississippi embayment in Independence County; however, Cretaceous deposits are believed to be present beneath younger formations throughout practically all the area treated in this report. The buried deposits are believed to be referable to the Upper Cretaceous, although in the center of the Mississippi embayment Lower Cretaceous deposits may intervene between the base of the Upper Cretaceous and the Paleozoic basement rocks.

The data available indicate that the Cretaceous deposits consist chiefly of argillaceous and sandy marls, sands, and clays of marine origin and attain their maximum thickness in the south-central part of the Mississippi embayment; according to the interpretation of logs of wells at Memphis, Tenn., the deposits have been penetrated from a depth of 1,135 feet to a depth of over 2,500 feet, showing here a thickness of over 1,300 feet.

The buried Cretaceous strata of this area are the northwestward and westward continuation of deposits that outcrop in Mississippi, Tennessee, Kentucky, and southern Illinois and the northeastward continuation of deposits that outcrop in southwestern Arkansas.

In southwestern Arkansas the Cretaceous deposits have been divided in ascending order into the Trinity sand of the Lower Cretaceous, and the Bingen sand, the Brownstown marl, the Annona chalk, the Marlbrook marl, the Nacatoch sand, and the Arkadelphia clay of the Upper Cretaceous. East of Mississippi River in the States enumerated the deposits have been divided in ascending order into the Tuscaloosa formation, the Eutaw formation, the Selma chalk, and the Ripley formation, all of Upper Cretaceous age.

[1] Miser, H. D., New areas of diamond-bearing peridotite in Arkansas: U. S. Geol. Survey Bull. 540, pp. 541–545, 1914.

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Only meager data have been obtained for differentiating into formations the buried Cretaceous strata of the Mississippi embayment. The marls encountered in wells along the western border of the area at Little Rock, Cabot, and Beebe contain a fauna corresponding in age to the fauna of the Nacatoch sand in southwestern Arkansas, of the Navarro formation in Texas, and of the typical Ripley strata exposed in Tippah County, Miss. The meager fauna found in surface outcrops in the vicinity of Newark, Independence County, is certainly of Upper Cretaceous age, and, although too imperfect to admit of an exact correlation, the containing beds probably represent the northward extension of the Nacatoch sand.

Deep wells, which are believed to have penetrated strata of Cretaceous age, have been drilled in Jackson, Arkansas, Craighead, Mississippi, and Poinsett counties, Ark.; at Memphis, Tenn.; and at Campbell, Dunklin County, Mo. (see pp. 42–44); a Cretaceous fossil has been obtained from an excavation at Cairo, Ill.

NACATOCH SAND (?).

GENERAL FEATURES.

The name Nacatoch is derived from Nacatoch Bluff on Little Missouri River, Clark County, Ark., and was first used by Veatch[1] for a series of Upper Cretaceous sands in southwest Arkansas, which intervenes between the Marlbrook marl and the Arkadelphia clay. According to Veatch, the formation corresponds approximately to the Washington greensand of Hill,[2] but the latter name was found to be preoccupied by the Washington County group described by Stevenson[3] in 1876.

In northeastern Arkansas the deposits regarded as representing this formation outcrop in the Grandglaise terrace in gullies and along valley slopes from near Magness and Newark in Independence County northeastward to the southern part of Lawrence County.

In southwestern Arkansas the formation outcrops in a belt 2 to 8 miles wide, extending from near Arkadelphia, Clark County, southwestward to the western part of Hempstead County.

In Independence and Lawrence counties the formation rests unconformably upon Paleozoic rocks of Carboniferous and pre-Carboniferous age, and is overlain unconformably by gravels of the Lafayette formation. The buried representatives of the formation in White, Lonoke, and Pulaski counties rest unconformably upon Carboniferous rocks and are overlain, probably unconformably, by Eocene strata and chiefly by the Midway formation.

[1] Veatch, A. C., Geology and underground water resources of northern Louisiana and southern Arkansas: U. S. Geol. Survey Prof. Paper 46, pp. 26, 27, 1906.

[2] Hill, R. T., The Neozoic geology of southwestern Arkansas: Arkansas Geol. Survey Ann. Rept., vol. 2, pp. 72–75, 1888.

[3] Pennsylvania Second Geol. Survey Rept. K, pp. 44–46, 1876.

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Where observed in outcrops in Independence County the formation consists mainly of glauconitic sands interbedded with drab or gray laminated clays. The glauconite is present in all stages of oxidation, rendering the sands reddish or brownish in color, and locally the beds are indurated to brownish, ferruginous sandstones. Iron carbonate concretions in various stages of oxidation were observed at one locality, and calcareous and fossiliferous layers occur locally in the formation.

The materials of the formation recognized in wells in White, Lonoke, and Pulaski counties (pp. 40, 41) consist of bluish-gray calcareous fossiliferous sandstones and clays.

Owing to the small extent and paucity of the exposures, little is known concerning the structure of the formation in central and northeastern Arkansas. However, considerations based on the general structure of the Mississippi embayment lead to the opinion that the strata strike approximately northeast and southwest parallel to the trend of the eastern border of the Ozark province, and dip slightly to the east or southeast away from that border.

In the vicinity of Newark, Independence County, the formation contains a few poorly preserved fossil mollusks and shark teeth, and a few species of mollusks have been obtained from the beds of the formation penetrated in wells in White, Lonoke, and Pulaski counties. The names of some of the more important fossils are given in the discussion of the correlation of the formation on page 42.

LOCAL DETAILS.

Independence County.—In valleys and gullies cutting the Grandglaise terrace, in the vicinity of Newark, Independence County, are exposures of greenish to reddish or brownish, more or less completely oxidized greensand, interbedded with subordinate layers and lenses of laminated drab clay, the age of which as shown by poorly preserved fossils is Upper Cretaceous. Several localities were examined in detail and are described in subsequent paragraphs.

Two miles north of Newark, on the upper road leading to Sulphur Rock, the following section is exposed in the road ditches on the west-facing slope of Thomas Creek valley along a distance of about one-quarter mile.

Section 2 miles north of Newark on upper road leading to Sulphur Rock; west-facing slope of Thomas Creek valley.

[Top of section 100± feet above level of Advance lowland, aneroid reading.]

	Feet.
Pliocene (?) (Lafayette formation):	
3. Heavy bed of gravel capping the hill east of the creek valley; consists mainly of angular to partially rounded brown, gray, and red pebbles and cobbles of chert and flint up to 6 inches or more in length; materials from this bed have drifted down over the valley slope to the base of the hill	25±

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Upper Cretaceous (Nacatoch sand?):	Feet.
2. Greenish-drab weathered clay, poorly exposed	25±
1. Dark-green to reddish or brownish, more or less oxidized, highly glauconitic sand, and drab laminated clay, the clay predominating in the upper 15 or 20 feet and the sand predominating in the lower 40 or 45 feet; the glauconite in the sand is present in all stages of oxidation from dark-green, slightly oxidized grains to completely oxidized grains; locally the sand is indurated to dark-brown ferruginous sandstone, and one such layer, 20 or 25 feet above the base, contains poorly preserved fossils, among which were recognized an unidentified coral, Exogyra (print of a small valve), *Turritella trilira* Conrad (?), and a shark tooth (field No. 270)	60
	110±

Two and one-half miles north of Newark, 20 or 25 feet of materials corresponding to layer No. 1 of the preceding section are exposed in a gully in a field just east of the road leading to Cord. The materials here consist of glauconitic greensand interbedded with layers of drab laminated clay, yellow ocher-like ironstone, and more or less completely oxidized concretions of iron carbonate, many of which have an unoxidized core. Ten or fifteen feet above the base of the section is a discontinuous concretionary layer of coarse, calcareous, glauconitic sandstone containing small black phosphatic pebbles and a few poorly preserved waterworn fossils; the individual lenses are several feet in length and 3 to 4 inches in thickness. The following Cretaceous fossils were recognized: *Ostrea tecticosta* Gabb, Ostrea sp. (young individual), and Anomia sp. (a ribbed form) (field No. 271).

In a gully on a public road leading west from the Magness-Sulphur Rock road, about 1 mile north of Magness and 3 miles west of Newark, the following section is exposed:

Section in public road leading west from the Magness-Sulphur Rock road, 1 mile north of Magness.

[Top of section 100± feet above level of Advance lowland, aneroid reading.]

Pleistocene (?) (loess?):	Feet.
Yellowish and brownish pebbly loam capping the hill	2–3
Pliocene (?) (Lafayette formation):	
Gravel composed of pebbles and cobbles of flint and chert up to 8 or 10 inches in length	3–4
Unconformity.	

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	Feet.
Upper Cretaceous (Nacatoch sand?):	
Red oxidized glauconitic sand, locally indurated to ferruginous sandstone, with interbedded subordinate layers of laminated clay	20
Gravel composed chiefly of pebbles of flint and chert, with some fragments of sandstone; the pebbles are angular to smoothly rounded, are gray, black, and brown, and reach 3 or 4 inches in length	½–1
Unconformity.	
Paleozoic (Carboniferous):	
Dark compact shale	15
	43±

Soft fossiliferous limestone or marl, which probably belongs to the Nacatoch sand, is encountered in wells at and near Newark. However, none of the fossiliferous material has been saved for examination. Specific localities where the material has been reported, are a well in Newark, where 3 feet of gray limestone or marl containing mollusks and shark teeth was penetrated between the depths 18 and 21 feet (see log, p. 194), and 2 miles north of Newark, where, in a phosphate prospecting pit, dug to an undetermined depth, a similar bed of marl was encountered.

The exposures described show that the body of the Grandglaise terrace in the vicinity of Newark is composed of strata of Upper Cretaceous age, probably representing the northward extension of the Nacatoch sand of southwest Arkansas. The Cretaceous is overlain by gravels of the Lafayette formation, reaching a maximum thickness of 25 or 30 feet, and above the latter is a thin layer, not everywhere present, of sandy and pebbly loam, believed to represent the loess of Crowleys Ridge.

Between Newark, Independence County, and Strawberry, Lawrence County, stratified sands and clays, probably of the same age as the Cretaceous strata in the vicinity of Newark, are exposed in places in the Grandglaise terrace, and have been examined at the following-described localities:

Three miles north of Newark, on the Newark-Powhatan road, alternating beds of sand and pinkish-gray clay rest upon Paleozoic sandstone.

In sec. 2, T. 13 N., R. 4 W., alternating beds of red sand and gray clay are exposed near the top of the terrace, which is here well developed and rises about 90 feet above Black River bottom.

Between Dota and Cord the terrace is 2 to 3 miles wide. Highly stratified sands and clays were observed to maximum heights of 70 to 90 feet above the level of Black River bottom; gravels of the Lafayette formation and yellow loams, probably representing the loess of Crowleys Ridge, overlie the sands and clays at many places.

Stratified sands and clays were observed in the vicinity of Saffel post office (now discontinued). Three-quarters of a mile north of

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Saffel a few feet of gray to blue clay, interstratified with red sand and overlain by 2 to 10 feet of yellow loam, is exposed; the loam resembles certain facies of loess in Crowleys Ridge and is believed to be of the same age as the loess (Pleistocene). The loam forms the surface material of the terrace from about 3 miles south of Saffel to Strawberry, in Lawrence County.

South of Independence County.—Most of the known data regarding the existence of buried deposits of Cretaceous age along the western border of the Mississippi embayment, south of Independence County, have been published by Harris.[1] With reference to specimens of marl encountered in wells at Beebe, White County, at depths not exceeding 64 feet, Harris says:

> A fragment of this marl from Beebe was obtained by the present writer from the State Survey collection, and when examined its Cretaceous characters were definitely ascertained. The matter was accordingly submitted to the Mesozoic Division of the United States Geological Survey, and Dr. T. W. Stanton reports finding in it the following species of Cretaceous (Ripley) fossils:
>
> Nucula percrassa Conrad.
> Gari? elliptica Gabb.
> Veleda lintea Conrad?
> Scaphites conradi (Morton).
> Baculites anceps Lamarck.
> Placenticeras sp.

Harris gives other data as follows:

> *Lonoke County.*—Among some material sent to the United States Geological Survey in 1890 by Dr. Branner are three or four fragments of *Exogyra costata* labeled "Well at Cabot Station, Iron Mt. R. R., Lonoke Co., Arkansas, sec. 18, 4 N., 9 W.; E. C. Buchanan, collector, April, 1873." Another package, marked "Well at Cabot, Hendricks," contains numerous specimens of an Anomia and *Cardium eufaulense?* and other more indistinct forms, all imbedded in a bluish gray calcareous sandstone resembling closely the concretionary rocks of the upper Ripley group.

From a well at Cabot, known as the Nusury well, owned by Mr. George P. Murrell, the junior author of the present report obtained fossiliferous material, taken between the depths of 20 and 46 feet, which on lithologic grounds are separable into dark-gray calcareous clay, with numerous fragments of shells, in part arranged in seams and pockets, and gray calcareous stndstone.

Among the poorly preserved fossils in the clay the senior author has identified the following forms: *Leda pinnaforma* Gabb, *Anomia argentaria* Morton?, Crassatellites sp., Cardium sp., *Cyprimeria depressa* Conrad, Scaphites sp. In the sandstone he recognized Nucula sp., Glycymeris sp. (young individual), Anomia sp. (ribbed form), and *Cardium eufaulense* Conrad.

In regard to the Cretaceous strata in Pulaski County, Harris says:

> *Pulaski County.*—It is at present impossible to say to what extent the Eocene deposits of Pulaski County are underlaid by Cretaceous. In the vicinity of

[1] Harris, G. D., The Tertiary geology of southern Arkansas: Arkansas Geol. Survey Ann. Rept. for 1892, vol. 2, pp. 10–15, 1894.

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Little Rock, however, there is good, though not absolutely positive evidence, that beneath the limestone layer of the Midway Eocene there are Cretaceous deposits from 10 to 30 feet in thickness. A package was sent to the United States Geological Survey by Dr. Branner, marked "J. S. Taylor's well, West 7th Street, near Bishop Street, Little Rock; E. C. Buchanan, collector, July, 1875," containing the following Cretaceous forms:

Anomia (as at Cabot).
Cardium eufaulense?
Leptosolen biplicata (Stanton's identification).
Turritella trilira.

The striking similarity between the matrix and fossils from this locality to those found at Cabot has led to the suspicion, though perhaps ungrounded, that all may have come from the latter place and at some time had been improperly labeled. Yet, even though this be true, there are other evidences which go far to show that there are Cretaceous deposits within the limits of the city of Little Rock.

Harris[1] also describes several exposures of bog iron ore, ferruginous sand and clay, and sand, which he believes to be of Cretaceous age, at several localities within the city of Little Rock. These beds underlie strata of undoubted Midway (Eocene) age and the ferruginous bed in places contains obscure casts of fossils, among which are questionably identified impressions of Baculites and *Exogyra costata*. These localities are as follows:

Intersection of Nineteenth Street or "Hot Springs road" and the St. Louis, Iron Mountain & Southern Railway; 10 feet of bog iron ore overlain by 20 feet of white and yellow sand.

The flanks of the depression in western Little Rock through which the St. Louis, Iron Mountain & Southern Railway passes.

The corner of Sixth and Wolfe streets; ferruginous concretions with obscure casts.

On Twelfth and Thirteenth streets, west of the St. Louis, Iron Mountain & Southern Railway, about 100 yards south of the Hot Springs road; ferruginous bed with indistinct impressions of fossils.

The data indicate the presence of Upper Cretaceous strata, probably representing the Nacatoch sand, at a relatively shallow depth along the western margin of the Mississippi embayment from Little Rock at least as far north as Beebe, White County.

CORRELATION.

Surface deposits in the vicinity of Newark, Independence County, have yielded the following species:

Species from Cretaceous deposits exposed near Newark, Independence County.

Unidentified coral.	Anomia sp. (ribbed form).
Ostrea tecticosta Gabb.	Turritella trilira Conrad (?)
Ostrea sp. (young individual).	Unidentified shark tooth.
Exogyra (print of small valve).	

[1] Harris, G. D., op. cit., pp. 13, 14.

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The fossils enumerated are characteristic Upper Cretaceous forms, but those identified specifically, with the possible exception of the ribbed Anomia, have rather wide vertical ranges within the Upper Cretaceous and are therefore not of much value in establishing an exact correlation with known sections elsewhere. In terms of the Upper Cretaceous section of southwestern Arkansas, both *Ostrea tecticosta* Gabb and *Turritella trilira* Conrad might be taken as indications of any one of the Upper Cretaceous formations, from the Brownstown marl to the Arkadelphia clay, inclusive. So far as known, the type of Anomia found at this place is restricted in range to the upper part of the Upper Cretaceous, and this form probably limits the possible correlation of the beds to either the Nacatoch sand or the Arkadelphia clay. The highly glauconitic character of the deposits, however, is strong though not conclusive evidence that they represent the northward extension of the Nacatoch sand.

This correlation is strengthened by the evidence afforded by certain of the Cretaceous fossils found in wells in Lonoke and White counties, such as *Exogyra costata* Say, *Gari? elliptica* Gabb, *Scaphites conradi* (Morton), and *Baculites anceps* Lamarck. (See p. 40.) In known sections these fossils are restricted in range and indicate that the containing beds are approximately synchronous with the Nacatoch sand. The deposits in the vicinity of Newark, Independence County, are believed to be the northward continuation of these buried strata.

CRETACEOUS STRATA PENETRATED IN WELLS AND EXCAVATIONS.

Well at Newport, Jackson County.—A 1,000-foot well at Newport, Jackson County, a log of which is given on page 197, passed through 500 feet of quicksand between depths of 155 and 655 feet; the quicksand is probably referable in part or in whole to the Cretaceous.

Well at Stuttgart, Arkansas County.—In 1906 and 1907 a 1,200-foot oil-prospecting well was drilled near Stuttgart, Arkansas County. (See incomplete log on p. 152.) Glauconitic sand, which may be referable to the Cretaceous, was penetrated between the depths of 950 and 1,078 feet.

Wells at Jonesboro, Craighead County.—At the city waterworks plant at Jonesboro, in Craighead County, two wells have been drilled to depths of 1,214 and 1,265 feet, respectively. An approximate log of the deeper well is given on page 169. It is believed that several hundred feet of Cretaceous strata were penetrated in the lower part of the boring.

Wells in Mississippi County.—Welis in Mississippi County at Blytheville (depth 1,448 feet), at Burdette (depth 1,495.5 feet), and at Wilson (depth 1,567 feet) entered the Cretaceous and probably

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penetrated several hundred feet of strata of that age in the lower parts of the borings. Incomplete logs of the Blytheville and Burdette wells are given on pages 225 and 226.

Well at Marked Tree, Poinsett County.—A 2,007-foot well at Marked Tree, in Poinsett County, probably penetrated not less than 1,000 feet of Cretaceous strata in its lower part. (See p. 245.)

Wells at Memphis, Tenn.—Several deep wells have been drilled at Memphis, Tenn. The logs of two of them, the depths of which are, respectively, 1,583 and 1,794 feet, are quoted on pages 176 and 177. In 1911–12 an oil-prospecting well was drilled on Old Hen and Chicken Island, near Memphis, to a depth of 2,500+ feet. No fossils have been obtained from these wells and the attempted correlations were based on the lithologic character of the materials penetrated. According to Ashley's interpretation of the log of oil-prospecting well No. 1 on Hen and Chicken Island, quoted on page —, 155 feet of blue clay, penetrated between the depths 980 and 1,135 feet, represents the Porters Creek clay (Eocene); 454 feet of sand and clay, sand predominating, between the depths 1,135 and 1,589 feet, represent the Ripley formation (Upper Cretaceous); clay and sand, clay predominating, between the depths 1,589 feet and the bottom of the well at 1,794 feet, represent the Selma chalk (Upper Cretaceous).

According to information obtained by correspondence with Mr. H. L. Armstrong, of Memphis, the oil-prospecting well on Old Hen and Chicken Island is believed to have completely penetrated the clay representing the Selma chalk at a depth of 2,375 feet, making a total thickness of 786 feet for this formation. If this interpretation is correct, the well penetrated at least 125 feet of the Eutaw formation which underlies the Selma.

Well at Campbell, Dunklin County, Mo.—A 960-foot well at Campbell, Dunklin County, Mo., a log of which is quoted on page 163, is believed to have penetrated Cretaceous strata. According to Shepard, who published the log, the lower 20 feet of the section is of Ripley (Upper Cretaceous) age, but possibly a part of the overlying clay is also of Cretaceous age.

Excavation at Cairo, Ill.—Definite evidence of the presence of Upper Cretaceous strata as far north as southern Illinois is afforded by a fossil shell found near Cairo, Ill. The following data are quoted from a paper by the senior author:[1]

> This specimen was discovered in an excavation for a bridge pier and later came into the possession of the State Museum at Springfield, Ill. Thence it was sent to Dr. C. A. White, at the National Museum, Washington, D. C., and was identified by him as *Exogyra costata* Say. Recently the specimen was again sent to Washington by request and was determined by the writer to be

[1] Stephenson, L. W., The Cretaceous deposits of the eastern Gulf region: U. S. Geol. Survey Prof. Paper 81, p. 18, 1914.

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a typical specimen of *Exogyra costata* var. *cancellata* Stephenson. The information given on the label accompanying the specimen is as follows: "Specimen No. 8358 of the State Natural History Museum, Springfield, Ill. Locality: Bottom of Ohio River; found in sinking a caisson for Illinois Central Railroad bridge near Cairo, Ill." The shell was not waterworn. Portions of the matrix in which the shell was originally embedded, adhering to the surface, consisted of fine, gray, calcareous, argillaceous, micaceous, marine sand. Although from the account of its discovery it can not be positively asserted that this specimen of Exogyra was in its original position in marine sand where found, the assumption that it was in place seems reasonable. Whether this marine sand exists as a lens in the predominantly shallow-water beds of the McNairy sand member [of the Ripley formation] or constitutes a northward extension of the stratigraphically lower, purely marine strata of the Ripley formation of Tennessee, which in Kentucky and Illinois have become overlapped and buried by the beds of the McNairy sand member, is not definitely known. However, on the assumption that the specimen belonged in place where found, the Cretaceous sea is shown to have extended, probably as a broad, open embayment, as far north as Cairo.

Tertiary system.

DISTRIBUTION.

Within the area here treated deposits of Tertiary age (Eocene) outcrop in Crowleys Ridge, in the upland southwest of Arkansas River, and, interruptedly, in a narrow belt along the western border of the Mississippi embayment from Little Rock, Pulaski County, at least as far northeast as the southern part of Independence County; if the scattered deposits of gravel which occur along the border of the Ozark province belong to the Pliocene, the Tertiary is represented all the way to the Arkansas line. Detailed descriptions of nearly all the more conspicuous exposures and of many of the less prominent ones have appeared in previous publications. It is not the purpose of this report to give a comprehensive account of all known localities of Tertiary rocks in the area, but those furnishing the most complete sequence of strata, those furnishing paleontologic data, and those which for other reasons are of especial interest will be described.

The Tertiary is represented by the Eocene series and, questionably, by the Pliocene series.

EOCENE SERIES.

FORMATIONS DIFFERENTIATED.

The Eocene deposits of the area have been differentiated only imperfectly, chiefly owing to lack of sufficient paleontologic data; however, evidence has been obtained to show the presence of strata representing the Midway, Wilcox, Claiborne, and Jackson formations.

The Midway formation outcrops along the western border of the Coastal Plain in the vicinity of Little Rock, Pulaski County, and

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in Lonoke, White, Jackson, and Independence counties. Undifferentiated strata of Eocene age outcrop in an elevated area in the northwestern part of Lonoke County.

Strata of Eocene age outcrop in places along the border of the Coastal Plain upland southwest of Arkansas River. These strata include the Midway formation in Pulaski County; undifferentiated Eocene strata in Pulaski, Sabine, Grant, and Jefferson counties; and the Jackson formation in Jefferson, Cleveland, and Lincoln counties.

The core of Crowleys Ridge, from a few feet to 100 feet or more above the level of the lowlands both east and west, is composed of irregularly and regularly bedded sands and clays, interbedded with subordinate layers and lenses of lignite. These deposits are of Eocene age and on the evidence of fossil plants and invertebrates may be roughly differentiated, in the ascending order of their age, into the Wilcox formation, the Claiborne formation, and the Jackson formation.

By combining paleontologic and physical criteria an attempt has been made to determine the areal distribution of each of the formations named, but the mapping is confessedly only an approximation to the true distribution.

MIDWAY FORMATION.

GENERAL FEATURES.

Name.—The name Midway[1] was first used by Smith and Johnson in 1887 for light-colored argillaceous limestone with projecting ledges and yellowish sands, exposed at Midway Landing and on Pine Barren Creek in Wilcox County, Ala., and traceable westward through Wil-

[1] The principal contributions to the subject of the Midway formation are listed below.

Smith, E. A., and Johnson, L. C., Tertiary and Cretaceous strata of the Tuscaloosa, Tombigbee, and Alabama rivers: U. S. Geol. Survey Bull. 43, pp. 62–67, 70, 1887.

Langdon, D. W., Geological section along the Chattahoochee River from Columbus to Alum Bluff: Georgia Geol. Survey First Report Progress, p. 95, 1891.

——— Variations in the Cretaceous and Tertiary strata of Alabama: Geol. Soc. America Bull., vol. 2, pp. 594, 595, 1891.

Spencer, J. W., Geological report on southwest Georgia: Georgia Geol. Survey First Report Progress, pp. 44–46, 1891.

Harris, G. D., The Tertiary geology of southwestern Arkansas: Arkansas Geol. Survey Ann. Rept. for 1892, vol. 2, pp. 8, 9, 22–54, 1894.

——— The Midway stage: Bull. Am. Paleontology, vol. 1, No. 4, pp. 115–270 (1–156), 1896.

Dall, W. H., A table of the North American Tertiary horizons, correlated with one another and with those of western Europe, with annotations: U. S. Geol. Survey Eighteenth Ann. Rept., pt. 2, p. 346, 1898.

Harris, G. D., and Veatch, A. C., A preliminary report on the geology of Louisiana: Louisiana Geol. Survey, pt. 5, pp. 63–73, 1899.

Vaughan, T. W., The Eocene and lower Oligocene coral faunas of the United States: U. S. Geol. Survey Mon. 39, p. 25, 1900.

Veatch, Otto, and Stephenson, L. W., Tertiary and Quaternary [Georgia]: Georgia Geol. Survey Bull. 26, pp. 216–226, 1911.

Vaughan, T. W., Texas, Louisiana, and Arkansas [Eocene of]: U. S. Geol. Survey Prof. Paper 71, pp. 723–725, 1912.

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cox and Marengo counties to Tombigbee River. The terrane as thus defined formed the basal member of the so-called "Lignitic" and rested on the Cretaceous. In 1894 Harris redefined the application of the name, making it include all the beds between the top of the Cretaceous and the base of the "Lignitic," the latter name being restricted to the lignite and leaf-bearing clays and sands. He says:

> The term "Midway series" was used by Smith and Johnson in 1887 to designate a calcareous formation lying at the base of the Eocene of Alabama, and was classified by them as a subdivision of the "Lignitic" (Eolignitic of Heilprin). Owing, however, to its persistent nature, occurring, interruptedly to be sure, from Georgia to western Texas, and to its generally marked lithological and paleontological differences from the remainder of "Lignitic" deposits, it seems advisable to make the terms of coordinate rank.

In a footnote he adds:

> It is quite probable that the Black Bluff and Matthews Landing beds in Alabama should be classed in the Midway stage.

The Flatwoods clays of Hilgard[1] in Mississippi, the Porters Creek group of Safford[2] in Tennessee, and the Middleton formation of Safford[3] in Tennessee, Mississippi, and Alabama, represent parts or all of the Midway formation.

Areal distribution.—In Arkansas the Midway formation has been traced in surface outcrops in a belt a few miles wide, extending from a point near Rockport, on Ouachita River (west of Malvern), in Hot Springs County, northeastward along the western border of the Gulf Coastal Plain to Little Rock, Pulaski County. Northeast of Little Rock the formation has been recognized in wells and in outcrops at the following places: Questionably in a well at Jacksonville, Pulaski County; in wells and in outcrops at and near Cabot, Lonoke County; questionably in a well at Beebe, White County; in outcrops in an area not exceeding one-half mile in width, extending from the vicinity of Bradford, White County, to Depart Creek, in the southern part of Independence County.

East of Mississippi River the Midway formation outcrops in a belt a few miles wide extending from central Georgia along the southern border of the area of outcrop of the Upper Cretaceous westward through Alabama and northward through Mississippi to Hardeman County, Tenn. From Hardeman County northward through Tennessee and Kentucky to southern Illinois the Midway is represented at least in part by the Porters Creek clay.

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[1] Hilgard, E. W., Agriculture and geology of Mississippi, 1860, pp. 110, 111: Am. Assoc. Adv. Sci. Proc., vol. 20, p. 222, 1871; Am. Jour. Sci., 3d ser., vol. 2, p. 391, 1871.

[2] Safford, J. M., The Cretaceous and Superior formations of west Tennessee: Am. Jour. Sci., 2d ser., vol. 37, pp. 368, 369, 1864.

[3] Safford, J. M., Notes on the Middleton formation of Tennessee, Mississippi, and Alabama: Geol. Soc. America Bull., vol. 3, pp. 511, 512, 1891.

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Stratigraphic relations.—The formation in Arkansas rests upon strata of Upper Cretaceous age, except immediately along the western border of the Mississippi embayment, where the beds overlap slightly on the Paleozoic rocks. This relation is determined on the evidence of Cretaceous fossils found in wells at Beebe, White County; at Cabot, Lonoke County; and at Little Rock, Pulaski County; and on the occurrence of strata of probable Cretaceous age immediately beneath beds of undoubted Midway age in outcrops at Little Rock. The nature of the contact between the Cretaceous and the Midway formation has not been determined by observation, but from paleontologic evidence the relation may be inferred to be that of nonconformity. The same marked faunal contrast exists here between the Upper Cretaceous and the Midway formation as exists in Alabama between the Ripley formation and the Midway formation, which are known to be separated by an unconformity of regional extent.

Southwest of Arkansas River the Midway formation is overlain by undifferentiated strata of Eocene age. Northeast of Arkansas River, along the western border of the Mississippi embayment, the formation is overlain in part by undifferentiated strata of Eocene age, in part by deposits of questionable Pliocene age (Lafayette formation), and in part by Quaternary alluvial deposits.

Lithologic characters.—The formation in Arkansas consists of gray, more or less sandy and argillaceous limestones, some layers of which are crystalline, interbedded with calcareous sand or friable sandstone and marl. Fossil mollusks and shark teeth characterize the terrane, and in places the molluscan remains are present in great numbers, either intact, in fragments, or as casts and impressions.

Strike, dip, and thickness.—The strike of the strata composing the Midway formation in Arkansas is approximately northeast-southwest, parallel to the western border of the Mississippi embayment. In single outcrops, all of which are small, the beds appear to be nearly horizontal; probably, however, they dip slightly to the southeast at right angles to the border of the Ozark province, this being the general attitude of the Eocene strata of the embayment with respect to the bordering Paleozoic rim. The formation doubtless extends southeastward beneath the younger Eocene and the Quaternary deposits and reaches greater depths in that direction.

The maximum observed thickness of the formation in the area is in a cut of the St. Louis, Iron Mountain & Southern Railway, one-fourth mile south of Grandglaise, Lonoke County, where 22 feet of strata is exposed.

Physiographic expression.—Where exposed in White, Lonoke, and Independence counties the formation forms the base of a more or less clearly defined terrace or ridge, designated the Grandglaise ter-

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race, the crest of which is 250 to 290 feet above sea level, or 40 to 80 feet above the level of the lowland to the east. The preservation of this erosion remnant is due, at least in part, to the relatively resistant character of the limestones of the formation.

Paleontologic character.—The formation is fossiliferous, yielding chiefly mollusks, although shark teeth are fairly abundant locally, and occasional fragments of crustaceans and echinoids have been found. The mollusks vary in their state of preservation from nearly perfect specimens to traces and fragments or molds and casts.

A list of the species identified from the formation is given in the discussion of correlation on page 53.

LOCAL DETAILS.

Pulaski County.—The Midway formation is exposed at numerous places in Little Rock and from Little Rock southwestward through Pulaski and Saline counties nearly to Rockport (west of Malvern) in Hot Springs County; in the same belt the formation is frequently reached in wells. Harris[1] has compiled the available data on this area, including the results of his own observations. The most complete section given by him is on Fourche Creek near the mouth of Crooked Creek, 8 or 9 miles southwest of Little Rock, in the NW. ¼ SW. ¼ sec. 8, T. 1 S., R. 13 W. He describes the locality in substance as follows:

Section on Fourche Creek, near the mouth of Crooked Creek, Pulaski County.

	Feet.
Soil	2
Yellowish and gray, more or less friable limestone; replete with *Enclimatoceras ulrichi* varying in size; the exterior of many of the fossils stained brownish by iron oxide	1½
Light-gray limestone containing innumerable specimens of *Ostrea pulaskensis* Harris	3
Light-yellowish and gray, somewhat sandy limestone, honeycombed and cavernous on weathered surface; at base replete with specimens of *Turritella mortoni* Conrad	8½
Light-yellowish calcareous sandstone forming a ledge	2½
White and black sand, tinged with yellow on the exterior, containing scattered blue nodules	2
Black shale exposed only at times of very low water	?
	19½+

[1] Harris, G. D., The Midway stage: Bull. Am. Paleontology, vol. 1, No. 4, pp. 130–132 (16–18), 1896.

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Fossils specifically identified from this locality are:

Fossils from Fourche Creek, near the mouth of Crooked Creek, Pulaski County.

Cucullæa macrodonta Whitfield.
Ostrea crenulimarginata Gabb.
Ostrea pulaskensis Harris.
Venericardia planicosta Lamarck.
Calyptraphorus velatus Conrad.
Natica alabamiensis Whitfield.
Turritella mortoni Conrad.
Turritella multilira Whitfield.
Turritella alabamiensis Whitfield.
Potamides alabamiensis Whitfield.
Tubulostium dickhauti White.
Enclimatoceras ulrichi White.
Callianassa ulrichi White.

Northeast of Little Rock the formation is thought to have been encountered in a well at Jacksonville located on the property of A. J. McBride and drilled in 1904; a log of this well has been furnished by the owner and is given on page 259. The limestone penetrated between the depths 70 and 82 feet probably belongs to the Midway formation.

Lonoke County.—In the vicinity of Cabot, Lonoke County, a limestone belonging to the Midway formation is known to occur at the surface, and limestones and marl, probably belonging in part to this formation, are encountered in numerous wells and cisterns. However, some of the marls penetrated in wells have been shown to belong to the Upper Cretaceous, which underlies the Midway. (See p. 40.) Logs of two wells at Cabot are given on page 217.

Harris[1] gives the following data:

Farther to the southwest, in Lonoke County, the Midway stage appears in the vicinity of Cabot. A specimen of more or less friable limestone collected by the survey is filled with fragments of oyster shells.

On the line between sec. 18, T. 4 N., R. 9 W., and sec. 13, T. 4 N., R. 10 W., midway of the line (station 2230), Mr. J. A. Taff obtained specimens of:

Ostrea (young shells).
Turritella mortoni (cast).
Shark teeth and vertebræ.
Fragment of light-gray firm limestone.

Mr. E. C. Buchanan collected at T. 3 N., R. 11 W., sec. 12, NW. ¼ of SW. ¼, about 600 feet northwest of Henry's store (station 2444), a specimen of limestone closely resembling those obtained at station 2436 [near Bradford, White County], though no fossils besides Ostrea are determinable in it.

White County.—At Beebe, White County, and for a mile or so west of that place, marl which may be referable in part to the Midway formation is struck in wells at depths of 25 to 40 feet. Upper Cretaceous fossils have been recognized, however, in specimens of marl from this place, and it is certain that the Midway, if present, is underlain by the Cretaceous. (See p. 40.)

[1] Arkansas Geol. Survey Ann. Rept. for 1892, vol. 2, pp. 25, 26, 1894.

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Call[1] has published a section constructed by combining a section exposed in a prospecting shaft, near Beebe, and the log of a near-by well. He says:

About 60 miles north of the Arkansas River localities just mentioned, near the village of Beebe, in White County, in T. 5 N., R. 8 W., SW. ¼ of SW. ¼ of sec. 5, there is exhibited a very instructive section in a shaft sunk to reach Eocene shell marls for commercial purposes. The locality is on the farm of Mr. Cyrus Heller. To the section as shown in the shaft there is added the record of a well driven a few hundred feet southwest of it. The position of the section near the western limit of the Tertiary area, which is less than 2 miles away, renders it of exceptional interest:

The section given by Call is in substance as follows:

Combined section of an exposure in a prospecting shaft near Beebe and the log of a near-by well.

	Thickness.	Depth.
	Feet.	*Feet.*
Humus	1	1
Whitish sandy clay, grading downward into red clay; in lower half, scattered pebbles of chert having a maximum diameter of 2 or 3 inches	10	11
Hard red, finely arenaceous clay	4	15
Light-colored stratified sandy clay containing an abundance of white chert pebbles and a few white sandstone pebbles	13	28
Argillaceous material with comminuted shell fragments; contains fragments of Dentalium, specifically undeterminable	1	29
Blue argillaceous material, with scattered pockets of greensand, containing an abundance of broken marine shells and a few perfect ones; recognized *Venericardia planicosta* Lamarck, *Turritella carinata* Lea [?]	35	64
(Unconformity).		
Soft blue shale of Carboniferous age; stopped drilling on hard white sandstone	47	111

The marl between the depths 29 and 64 feet is probably separable into two parts, the upper representing the Midway formation, from which the Tertiary fossils recognized by Call were taken, and the lower representing the Upper Cretaceous, from which the specimen of marl mentioned by Harris (p. 40) was taken.

In the northern part of the county, near the town of Bradford, on the St. Louis, Iron Mountain & Southern Railway, limestone of the Midway formation appears at the base of the narrow terrace or ridge known as the Grandglaise terrace. Northward from Bradford the first outcrops of the limestones are on the south and north side of a small creek which cuts the terrace, and from this place northward through Jackson County to the southern part of Independence County there are numerous outcrops of the rocks. The formation consists of ledges of limestone interbedded with gray calcareous unconsolidated sand.

The town of Bradford is underlain by the limestone which is encountered in wells; in a well on the property of W. D. Plant the rock

[1] Call, R. E., The geology of Crowleys Ridge: Arkansas Geol. Survey Ann. Rept. for 1889, vol. 2, pp. 14–17, 1891.

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was reached at a depth of 20 feet and extended to a depth of 40 feet, where shale of Paleozoic age was encountered.

The following is a generalized section of the terrace at Bradford:

Generalized section at Bradford.

	Feet.
Top of terrace capped with gravel (Lafayette formation?).	
Red calcareous clay (Eocene)	5–10
Gray calcareous clay (Eocene)	5–20
Layers of limestone interbedded with unconsolidated sand (Midway formation)	20±
Thin layer of gravel consisting of pebbles and cobbles of soft brown sandstone which range in size up to 6 or 8 inches in diameter, with an average diameter of one-half to 1 inch; these are derived from rocks of Paleozoic age	½–1
Unconformity.	
Sandstone and shale of Paleozoic age	1+

West of Bradford the Midway formation rests against the Paleozoic rocks along a steep eastward-sloping contact which probably represents an ancient sea cliff.

Along the east side of the Grandglaise terrace at Bradford the alluvial deposits of the Advance lowland rest unconformably against the Midway strata; here also the contact slopes steeply eastward and represents an erosion cliff produced by the meandering of Pleistocene and Recent streams which traversed the lowland.

Harris[1] gives the following data in regard to exposures near Bradford:

At an old limestone quarry by the side of the railway, 1¼ miles north of Bradford, specimens of *Turritella mortoni* composed of crystalline calcite are of frequent occurrence; an indistinct cast of a cardium was also noted at the last-named locality.

One-eighth of a mile nearer Bradford, perhaps 200 yards west of the railway track, many bowlders of highly crystalline limestone are strewn about in a field. Besides innumerable fragments of molluscan forms, this limestone incloses rounded pebbles of greenish sandy shale with major diameters in some instances of no less than 2 inches. The recognizable fossils are:

Ostrea præ-compressirostra Harris [=O. crenulimarginata Gabb].
Venericardia planicosta Lamarck (small).
Psammobia (large and ill defined).

Jackson County.—The Grandglaise terrace is well developed in the vicinity of Grandglaise, Jackson County, although at most places small branch valleys partly separate the terrace from the Paleozoic rocks to the west. The following section of the Midway formation

[1] Arkansas Geol. Survey Ann. Rept. for 1892, vol. 2, p. 25, 1894.

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is exposed in a cut of the St. Louis, Iron Mountain & Southern Railway one-fourth mile southwest of the station (see Pl. V, *A*):

Section in a cut of the St. Louis, Iron Mountain & Southern Railway one-quarter mile south of Grandglaise.

	Feet.
Top of hill and slope covered with brownish sandy loam and overgrown with vegetation	25
Midway formation:	
2. Limestone in layers 1 to 1½ feet thick, interbedded with thinner layers of soft gray calcareous sand; the limestone contains small greenish pebbles of sandstone which are particularly abundant in layers 5 to 8 feet above the base; the upper and lower surfaces of the limestone layers present numerous rounded and irregular concretionary projections which extend upward and downward into the intervening layers of sand; the limestones contain an abundance of imperfectly preserved fossil remains, among which T. W. Vaughan has identified the following: Belanophyllia sp., *Tornatellæa bella* Conrad, *Turritella mortoni* Conrad, and *Mesalia pumila* (Gabb) (field No. 272)	22
1. Concealed to the level of the Advance lowland	10
	57

The following is another section exposed about one-half mile southwest of Grandglaise; the part of the section above the limestone is obscured by weathering and is difficult to interpret:

Section exposed in a south-facing slope and railroad cutting just west of the St. Louis, Iron Mountain & Southern Railway, about one-half mile south of Grandglaise.

	Feet.
Pleistocene (loess?):	
6. Slope concealed by vegetation	10
5. Reddish massive, finely arenaceous and argillaceous loam resembling loess in texture; appears to grade downward into the next layer	12
Pliocene (?) (Lafayette formation):	
4. Red ferruginous argillaceous pebbly sand becoming very pebbly in the basal 1 to 2 feet; the pebbles consist of greenish sandstone and chert not exceeding 2 or 3 inches in diameter and not averaging over one-half inch in diameter	5
Eocene (?) (Midway formation?):	
3. Massive greenish-gray fine sand, oxidized to red in upper portion	8
Eocene (Midway formation):	
2. Limestone interbedded with sand, corresponding to the limestone described in the preceding section	5
1. Concealed to the level of the Advance lowland	10
	50

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A. PEBBLY LIMESTONE WITH INTERBEDDED LAYERS OF CALCAREOUS SAND BELONGING TO THE MIDWAY FORMATION, ON THE ST. LOUIS, IRON MOUNTAIN & SOUTHERN RAILWAY A QUARTER OF A MILE SOUTH OF GRANDGLAISE, JACKSON COUNTY.

B. SANDS, CLAYS, AND LIGNITES OF THE WILCOX FORMATION ON BOLIVAR CREEK NEAR ITS POINT OF EMERGENCE FROM CROWLEYS RIDGE, 3½ MILES NORTH OF HARRISBURG, POINSETT COUNTY.

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Exposures of limestone of the Midway formation, ranging from poor to fair, were observed along the eastward-facing slope of the Grandglaise terrace for a distance of about 2½ miles southwest of Grandglaise.

About one-half mile west of Grandglaise there is a poor exposure of limestone belonging to the Midway formation at the foot of the northwest-facing slope of a small branch valley which partially separates the ridge from the Paleozoic hills to the west.

Harris[1] gives the following data regarding two localities south of Grandglaise in Jackson County:

> Going southward toward Bradford the limestone ledges become more and more fossiliferous. Dr. J. C. Branner, in 1887, collected specimens from two points in this vicinity, giving as localities "Between 2 and 3 miles north of Bradford on the Iron Mountain Railway," and "Two miles north of Bradford on the Iron Mountain Railway." The former (station 2223, U. S. National Museum register) consist of light-gray limestone fragments holding on their ferruginated exterior numerous specimens of *Turritella mortoni* (composed of calcite) and coral.
>
> At the latter locality (station 2229) the following forms were recognized:
>
> Ostrea sp. (young).
> Cytherea sp. (a cast).
> Turritella mortoni Conrad.

Independence County.—The Midway formation extends from Jackson County northward into the southern part of Independence County. Harris[2] says:

> In Arkansas the Midway stage forms a low, terrace-like elevation on the northeast flank of the Paleozoic upland just to the south and southwest of Bayou Departe, Independence County.

CORRELATION.

The fossils of the terrane have been studied chiefly by Harris[1] and also by T. Wayland Vaughan. They have identified the following species:

Fossils from the Midway formation of Arkansas.

Belanophyllia sp. (identified by Vaughan).
Cucullæa macrodonta Whitfield.
Ostrea crenulimarginata Gabb.
Ostrea pulaskensis Harris.
Pecten alabamiensis Aldrich.
Venericardia planicosta Lamarck.
Calyptraphorus velatus (Conrad).
Tornatella bella Conrad (identified by Vaughan).
Natica alabamiensis Whitfield.
Turritella alabamiensis Whitfield.
Turritella mortoni Conrad.
Turritella multilira Whitfield.
Mesalia pumila (Gabb) (identified by Vaughan).
Potamides alabamiensis Whitfield.
Tubulostium dickhauti White.
Volutilithes limopsis Conrad?
Volutilithes petrosa (Conrad)?
Enclimatoceras ulrichi White.
Calianassa ulrichi White.

[1] Arkansas Geol. Survey Ann. Rept. for 1892, vol. 2, pp. 24, 25, 1894.
[2] Idem, p. 24.

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Harris, on the evidence of the species identified by him, has correlated the formation in Arkansas with the Midway formation of Alabama.

Of the fossils from the section one-quarter mile southwest of Grandglaise (p. 52) Vaughan states:

> The species are all known to occur in both the Midway and the overlying Wilcox, but *Mesalia pumila* Gabb does not range above the basal Wilcox; the collection offers no evidence opposed to the correlation of Harris.

WILCOX FORMATION.

GENERAL FEATURES.

Name.—The name Wilcox is derived from Wilcox County, Ala., and was proposed by A. F. Crider[1] in 1906 for 850 feet of "highly stratified, siliceous sands, laminated clays of various colors interstratified in places with beds of lignite, and lignitic clays," interposed between the Midway group below and the Claiborne group above.

Other terms which have been applied to the formation defined by Crider are "Northern Lignitic group,"[2] which is objectionable

[1] Geology and mineral resources of Mississippi: U. S. Geol. Survey Bull. 283, pp. 25–28, 1906.

[2] Literature on the "Lignitic group":

Safford, James M., Geological reconnaissance of the State of Tennessee: First report, pp. 162–163, 1856.

Hilgard, E. W., A report on the geology and agriculture of the State of Mississippi, pp. 110–123, 1860.

Hilgard, E. W., On the Tertiary formations of Mississippi and Alabama: Am. Jour. Sci., 2d ser., vol. 43, pp. 34–39, 1867.

Hilgard, E. W., Geological history of the Gulf of Mexico: Am. Jour. Sci., 3d ser., vol. 2, pp. 394–396, 1871.

Smith, E. A., Summary of the lithological and stratigraphical features and subdivisions of the Tertiary of Alabama: Introduction to Alabama Geol. Survey Bull. 1, pp. 10–14, 1886.

Smith, E. A., and Johnson, L. C., On the Tertiary and Cretaceous strata of the Tuscaloosa, Tombigbee, and Alabama rivers: U. S. Geol. Survey Bull. 43, pp. 18, 38–67, 1887.

Loughridge, R. H., Report on the geological and economic features of the Jackson Purchase region: Kentucky Geol. Survey, pp. 41–52, 1888.

Spencer, J. W., Geological report on southwest Georgia: Georgia Geol. Survey First Rept. progress, p. 43, 1891.

McGee, W J, The Lafayette formation: U. S. Geol. Survey Twelfth Ann. Rept., pt. 1, pp. 415–418, 1891.

Clark, W. B., Correlation papers—Eocene: U. S. Geol. Survey Bull. 83, 173 pp., 1891.

Harris, G. D., The Tertiary geology of southern Arkansas: Arkansas Geol. Survey Ann. Rept., 1892, vol. 2, pp. 55–86, 1894.

Smith, E. A., Phosphates and marls of Alabama: Alabama Geol. Survey Bull. 2, pp. 47–50, 1892.

Smith, E. A., Langdon, D. W., and Johnson, L. C., On the geology of the Coastal Plain of Alabama: Alabama Geol. Survey Bull., pt. 1, pp. 147–192, 198–202, 488–491, 1894.

Vaughan, T. Wayland, The stratigraphy of northwestern Louisiana: Am. Geologist, vol. 15, p. 209, 1895.

Harris, G. D., The lignitic stage: Bull. Am. Paleontology, vol. 2, No. 9, pp. 1–36, 1897.

Harris, G. D., and Veatch, A. C., A preliminary report on the geology of Louisiana: Louisiana Geol. Survey, pt. 5, pp. 64–73, 1899.

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because it is a lithologic and not a geographic term; Lagrange,[1] a term of broader significance than Wilcox, as it is known to include strata of Wilcox, Claiborne, and probably Jackson age; and "Chickasawan formation,"[2] also a term of broader significance than Wilcox.

The extension of the Wilcox formation into Georgia has been described by Veatch and Stephenson.[3]

A summary statement regarding the occurrence of the Wilcox formation in southwest Arkansas, Louisiana, and Texas has been given by Vaughan.[4]

Areal distribution.—The Wilcox formation outcrops in the basal portion of the east and west slopes of Crowleys Ridge and in the valley slopes of the larger streams cutting the ridge, from the vicinity of Harrisburg, Poinsett County, northward through Arkansas and Missouri to the northern extremity of the ridge in Stoddard County, Mo. East of Mississippi River the formation outcrops in a belt extending from west-central Georgia westward through Alabama and northward through Mississippi, Tennessee, and Kentucky to southern Illinois. From northern Mississippi northward the formation has not been accurately differentiated from the overlying deposits of Claiborne and Jackson age, all of which are included in the Lagrange formation.

Stratigraphic relations.—The basal portion of the formation in Arkansas does not appear at the surface, and for this reason its relations to underlying older formations have not been observed. However, from general considerations it is believed that the formation rests upon either older Eocene strata corresponding in age to the Midway formation or, if these are absent, upon strata of Upper Cretaceous age. At the northern extremity of Crowleys Ridge the terrane laps over upon rocks of Paleozoic age. Toward the southern limit of its areal extent in Crowleys Ridge the formation is overlain, probably unconformably, by the Claiborne formation.

Throughout its extent in Crowleys Ridge the formation is overlain unconformably by irregularly bedded sands and gravels belonging to the Lafayette formation (Pliocene?), or by disturbed materials derived from the Lafayette formation and the loess, which have found their way down over the slopes of the ridge by either redeposition, creep, or landslide.

Lithologic characters.—The formation in Crowleys Ridge is composed of irregularly bedded sands, locally indurated to sandstones

[1] Safford, J. M., Geology of Tennessee, pp. 424–426, Nashville, 1869.

[2] Dall, W. H., A table of the North American Tertiary horizons, correlated with one another and with those of western Europe: U. S. Geol. Survey Eighteenth Ann. Rept., pt. 2, pp. 344–345, 1898.

[3] Veatch, Otto, and Stephenson, L. W., Tertiary and Quaternary [Georgia]: Georgia Geol. Survey Bull. 26, pp. 226–235.

[4] Vaughan, T. W., U. S. Geol. Survey Prof Paper 71, pp. 725, 726, 1912.

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and quartzites, and irregularly bedded clays, with interbedded layers of lignite. From Jonesboro northward there are no exposures showing the complete sequence of strata composing the ridge, but from numerous small exposures examined in the area it seems apparent that the heavier beds of clay all occur at the base of the ridge and that beds of sand predominate above the clays. The clays vary in color from almost white to very dark, are lignitic in places, and in places are interbedded with layers of fairly pure lignite. Silicified stumps and logs have been observed in clay at one locality in the northern part of Greene County (p. 58).

The sands where unweathered are light in color, but on weathered surfaces are varicolored, presenting many shades between white and dark red or brown. Locally the sands have been indurated to sandstones, ranging in hardness from very soft rock to extremely hard quartzites. These rocks are exposed principally along the west slope of the ridge from Craighead County northeastward to the southern part of Clay County. The distribution of the quartzites in Arkansas is discussed in detail by Call.[1] (See also p. 61 of this report.) Marbut[2] has described similar quartzites near the northern extremity of the ridge in Stoddard County, Mo.

As shown by the Bolivar Creek exposure, 3½ miles north of Harrisburg (p. 62), the sands in the upper part of the formation become finer and more argillaceous than those at lower levels.

Strike, dip, and thickness.—Owing to the irregular bedding of the deposits composing the formation and also to the paucity of exposures, the strike of the strata can not be determined by observation; it is inferred, however, from the general structure of the embayment that the beds strike about northeast-southwest and dip to the southeast at the rate of a few feet per mile.

No data are available for determining the thickness of the terrane. In Mississippi the thickness was estimated by Crider to be 850 feet. Wells at Jonesboro, Craighead County, Ark. (1,265 feet deep), and at Campbell, Dunklin County, Mo. (960 feet deep), probably passed entirely through the formation and entered underlying older formations, but the information furnished by the wells is not sufficient to determine the position of the contact. Probably the thickness is not less than 500 feet nor greater than 1,000 feet.

Physiographic expression.—From Poinsett County northward the formation makes up the basal portion of Crowleys Ridge, and the steep and rugged character of the western side of the ridge is due, at

[1] Call, R. E., The geology of Crowleys Ridge: Arkansas Geol. Survey Ann. Rept. for 1889, vol. 2, pp. 90–102, 1891.

[2] Marbut, C. F., The evolution of the northern part of the lowlands of southeastern Missouri: Missouri Univ. Studies, vol. 1, No. 3, p. 26, 1902.

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least in part, to the interbedded masses of quartzite and the heavy beds of clay which outcrop in places along the lower slopes. The existence of this part of the ridge is doubtless due to the resistance offered by the Wilcox strata to the meandering and actively eroding rivers of Pleistocene and Recent times. The present detailed surface features of the ridge, however, are determined mainly by the younger Lafayette formation and the loess which cap and blanket the greater part of the crest and slopes.

Paleontologic character.—The formation has yielded fossil leaves at three localities (see pp. 58, 59, 62); at the two more northerly localities the fossils exist as poor to well-preserved impressions in soft sandstone. At the Bolivar Creek locality (p. 62) leaf impressions and lignitized leaves are contained in chocolate-colored clays. Lignite is common in the formation, and a few beds of lignite a few inches to 5 feet in thickness have been observed or have been penetrated in wells in the area. In places the quartzites and sandstones of the formation are perforated with small cavities believed to be the impressions of rootlets. Silicified stumps of trees and logs have been observed in clay at one place (p. 58). A list of the species of fossil plants found in the formation is given on page 63 of this report.

LOCAL DETAILS.

Missouri.—Marbut[1] has described clays (or shales) and sands, probably belonging to the Wilcox formation, which constitute the basal portion of Crowleys Ridge in its northern extension in Missouri. The clays where observed outcrop in the base of the ridge and range in color from gray to black. They are overlain by irregularly bedded sands, which are locally indurated to sandstones and quartzites.

Clay County.—The most northerly exposure of the formation in Arkansas, and probably the lowest one stratigraphically, is at Chalk Bluff, on St. Francis River, in the northeastern part of Clay County. Call[2] describes this bluff as follows:

> The summit is crowned with fine gravel and coarse sands. The sands are all variegated, more or less indurated, false bedded where seen in good section, and are separated by thin strata of white and drab pipe clays into two or three beds of variable thickness. In places on the steeper and barren hillsides this clay is washed over the face of the hills and gives to them a white appearance, which doubtless gave the place the name of Chalk Bluff. Along the river front and in the deeper ravines of the east face of the bluff are the regularly stratified bluish and drab-colored clays of Tertiary age, containing a few fragments

[1] Marbut, C. F., The evolution of the northern part of the lowlands of southeastern Missouri: Missouri Univ. Studies, vol. 1, No. 3, pp. 21–27, 1902.

[2] Call, R. E., The geology of Crowleys Ridge: Arkansas Geol. Survey Ann. Rept. for 1889, vol. 2, p. 115, 1891.

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of lignite. No fossils of any sort were to be found. Erosion has been great enough to expose these clays along the river banks and to a height of 35 to 40 feet in the deep ravines.

A small exposure of fossiliferous sandstone on the west-facing slope of Crowleys Ridge, 3 or 4 miles southwest of Boydsville, Clay County, is of much geologic interest. The outcrop is in the woods at the head of a small ravine about 100 yards west of the old Boydsville-Gainesville road and about one-fourth mile southwest of the point where the road crosses a small branch, the valley of which is cut down almost to the level of the lowland to the west. The exposure is inconspicuous, and anyone seeking the place should search along the slope from the branch just mentioned southward, following up each small ravine until he finds the outcrop.

The material consists of about 6 feet of soft, friable, stratified sandstone, splitting fairly well along the bedding planes and containing an abundance of well-preserved leaf impressions. The base of the exposure is 20 or 25 feet above the level of the lowland west of Crowleys Ridge and about 80 feet lower than the highest point of the road immediately to the east.

The locality was visited by E. W. Berry and the senior author, and the following species, identified by Mr. Berry, were collected:

Fossil plants from Crowleys Ridge, 3 or 4 miles southwest of Boydsville, Clay County.

Anemia eocenica Berry.[1]
Banksia tenuifolia Berry.[1]
Dryophyllum tennesseensis Berry.[1]
Nectranda lowei Berry.[1]

Mr. Berry states that these species are all common in the Wilcox formation of the eastern Gulf region.

Greene County.—Silicified stumps and logs of trees in clay of the Wilcox formation in the SW. ¼ SW. ¼ sec. 35, T. 19 N., R. 5 E., have been described by Call.[2] This locality is on the west slope of the ridge near the valley of Cache River, 6 or 7 miles north of Gainesville. Call says:

A hill of Tertiary blue clay rises about 40 feet above the bottomlands at this place. In cross section these clays are regularly and horizontally stratified, with little or no sand. Imbedded in this clay near the summit of the hill is a large stump of silicified wood, in place as it grew, with all its roots still imbedded and ramifying in every direction. Some 50 feet away, and at a point a little lower, occurs another stump, similarly disposed, and near at hand are two or three silicified logs. In the banks of a small stream about 300 feet south are many fragments of silicified woods, some of which are very large. The largest of these stumps has a diameter of 4 feet, and some of the logs are

[1] For description of this new species see Berry, E. W., The lower Eocene floras of southeastern North America: U. S. Geol. Survey Prof. Paper 91 (in press).
[2] Call, R. E., op. cit., p. 102.

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scarcely smaller. The complete erosion of the overlying Pleistocene and the upper members of the Tertiary sands leaves this hill a singular feature of the ridge. Nothing like it has been seen elsewhere. A thin soil covers the clays, and this supports a stunted growth of oaks. Samples of this wood were examined by Prof. Knowlton and were found to represent a new species, to which he has given the name *Cupressinoxylon calli*.

An exposure of lignite in the Wilcox formation not far from the preceding is described by Call[1] as follows:

In sec. 36, T. 19 N., R. 6 E. [R. 5 E. (?)], in a small stream which is but a few feet above the general level of the Cache bottoms, is an outcrop of lignite about 3 feet in thickness. The outcrop is in the base of the hill and the bed disappears beneath the surface of the water. It is quite black when wet, but dries to a brownish black. It crumbles into small fragments on exposure to the air. Above it are about 15 feet of Tertiary clays, and above these the usual Orange sands [Wilcox]. A short distance down the stream it is underlain by a bed of light-drab fire clay.

Another exposure of fossiliferous rock similar to the Boydsville locality is near Hardys Mill, 3 or 4 miles west of Gainesville, Greene County, in sec. 30, T. 18 N., R. 5 E. Call[2] describes this locality as follows:

It is about one-half mile from Hardys Mill and on the face of a steep hill fronting west. The outcrop is a coarse sandstone, capped by a compact, fine-grained, very hard sandstone containing numerous casts and impressions of vegetable origin. While there is a rude resemblance to certain forms of water plants in the character and arrangement of these remains, there is not left sufficient structure on which to base an opinion as to their real affinities. But below this siliceous layer there is a heavy layer of sandstone of coarser texture, and not so much metamorphosed, in which occur numerous remains of fossil plants. Those remains are mainly in the form of impressions of leaves of dicotyledonous plants.

Call collected specimens of fossil plants from this locality and sent them to the U. S. National Museum. The collection was recently examined by E. W. Berry, who identified the following species:

Fossil plants from near Hardys Mill, Greene County.

Aralia notata Lesquereux.
Cinnamomum postnewberryi Berry.[3]
Ficus eolignitica Berry.[3]
Ficus vaughani Berry.[3]
Pteris eolignitica Berry.[3]

Berry states that one of the forms enumerated occurs in the Fort Union formation of the western interior and that the remainder are common in the Wilcox formation of the eastern Gulf region.

[1] Call, R. E., op. cit., p. 103.
[2] Idem, pp. 95, 96.
[3] For description of this new species see Berry, E. W., The lower Eocene floras of southeastern North America: U. S. Geol. Survey Prof. Paper 91 (in press).

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Another section described by Call[1] in sec. 30, T. 18 N., R. 5 E., is about one-half mile distant from the Hardys Mill locality and is known as the Lovelady Place. The section, which reveals both clays and sands of the Wilcox formation, is as follows:

Section at the Lovelady Place, Greene County.

	Feet.
4. Light-colored thin soil, with much chert, supporting a heavy growth of pines	2
3. Hard coarse sandstone, identical with that at Hardys Mill; weathering greenish, softer below, regularly stratified	10
2. Soft cross-bedded particolored sands, red predominating, with numerous irregular patches of pure-white sand; becomes argillaceous toward base	20
1. Clay, sandy at top, less sandy below, light drab in color, becoming darker below and ending in a bed of lignite; the whole is regularly and horizontally stratified	25
	57

Layers 1, 2, and 3 of the section belong to the Wilcox formation.

On Poplar Creek, in Greene County, is an exposure described by Call,[2] which shows a ferruginous phase of the Wilcox and also the relation of this formation to the overlying Lafayette. The section is as follows:

Section on Poplar Creek, Greene County.

[NW. ¼ sec. 10, T. 16 N., R. 4 E.]

	Feet.
Pliocene (?) (Lafayette formation):	
4. Light-colored sandy humus with a few pebbles	3
3. Gravel with subordinate lenses of clay; much coarse sand is distributed throughout the gravel	10
2. Gravel and sand indurated to a conglomerate	1
Eocene (Wilcox formation):	
1. Cross-bedded, variegated, slightly indurated sands, white and yellow predominating, with scattered small masses of slate-colored pipe clay; locally cemented by iron oxide into hard, compact masses	12
	26

Craighead County.—From Craighead County northeastward to the southern part of Clay County exposures of quartzite, most of which are on the west-facing slope of the ridge, are numerous. These exist as masses of indurated sand in the Wilcox formation.

One of the best examples of the rock is in sec. 9, T. 15 N., R. 3 E., on the old William Lane place, about 4 miles northeast of Bono post office, Craighead County, where several large masses of extremely

[1] Call, R. E., op cit., pp. 97, 98.

[2] Idem, p. 111.

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hard, cross-bedded quartzite, 5 or 6 feet thick, outcrop on the western slope of the ridge just north of the public road. The base of the lowest mass is 20 or 25 feet above the level of the lowland to the west and the top of the highest one is about 40 feet above the same datum. The lowest mass is apparently not in its original position, but has slipped down the slope for an unknown distance; it is underlain by yellow stratified sand.

Just south of the road and a few rods south of the quartzite masses the following section is exposed in a gully, the bottom of which is only a few feet above the level of the lowland to the west:

Section in a gully on the William Lane place, ¼ miles northeast of Bono, Craighead County.

	Feet.
Pleistocene:	
Yellow and brown loam, a facies of the loess	4
Pliocene (?) (Lafayette formation):	
Heavy bed of coarse gravel, consisting chiefly of pebbles, cobbles, and bowlders of chert, with a considerable admixture of quartzite fragments derived from the Wilcox formation; a few smoothly rounded quartz pebbles occur mixed through the gravel	15
Unconformity.	
Eocene (Wilcox formation):	
Laminated gray and yellow fine argillaceous sand with subordinate lenses of laminated clay; a thin layer of brown ferruginous sand, locally indurated, occurs along the top of this bed	15
	34

Exposures of quartzite.—Exposures of the quartzites of the Wilcox formation have been noted by Call[1] and others at the following places:

Craighead County, secs. 6, 7, T. 14 N., R. 3 E.
secs. 9, 16, 17, 20, 29, 31, 32, T. 15 N., R. 3 E.
Greene County, secs. 4, 5, 16, 17, 19, T. 16 N., R. 5 E.
secs. 1, 3, 25, 36, T. 17 N., R. 4 E.
secs. 13, 23 ?, 34, 35, 36, T. 18 N., R. 4 E.
secs. 2, 4, 7, 8, 9, 18, 30, T. 18 N., R. 5 E.
Greene and Clay counties, secs. 15?, 19, 20, 29, T. 19 N., R. 6 E.

Poinsett County.—Call describes a section on Bolivar Creek in Poinsett County, 3½ miles north of Harrisburg (NW. ¼ SW. ¼ sec. 8, T. 11 N., R. 4 E.), concerning which he says:[2]

By far the best section exhibited in Poinsett County is on Bolivar Creek, 3½ miles north of Harrisburg, on the west side of the ridge. Bolivar Creek is the largest stream in this part of the county and constitutes the main tributary to, or is, rather, the chief source of the L'Anguille River. The exposure faces north

[1] Call, R. E., op. cit., pp. 93, 94. [2] Idem, pp. 80, 81.

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and is continuous for about 400 feet. The relations given in the section, however, are made out from observations extending over a mile, and represent a vertical distance of more than 100 feet. The point at which the lignite bed is exposed is only about 30 feet in height, but it underlies a vertical cliff at that place.

This locality was visited by the senior author, and the following section, which pertains only to the main exposure near the mouth of the creek, is based upon his observations (see Pl. V, *B*, p. 52):

Section on Bolivar Creek, 3½ miles north of Harrisburg, in north-facing bluff near the exit of the creek from Crowleys Ridge.

	Feet.
Pleistocene (loess):	
11. Brown loam, probably creep from a higher level	1
Pliocene (?) (Lafayette formation):	
10. Gravel, probably creep from a higher level	4
Eocene (Wilcox formation):	
9. Weathered brown fine argillaceous sand	3
8. Fine light-gray, faintly laminated argillaceous sand	11
7. Fine light-gray massive sand	4.5
6. Fine chocolate-colored argillaceous, faintly laminated sand	4.5
5. Dark chocolate-colored, very fine, very argillaceous sand	4
4. Dark-brown to black lignite	5
3. Brown argillaceous lignitic sand	1
2. Dark chocolate-colored tough clay, lignitic in upper portion; in places in the upper 2 feet contains numerous poorly preserved lignitized leaves and leaf impressions	3
1. Very tough light-greenish clay	2
	43

The layer of lignite (No. 4) and the clay layers (Nos. 1 and 2) are somewhat irregularly bedded and vary in thickness along the face of the bluff. In places the upper lignitic portion of layer No. 2 becomes a bed of true lignite 1 to 2 feet thick; a few lignitized logs and fragmental remains of lignitized stumps were seen in this layer.

Among the fossil leaves collected from layer No. 2, E. W. Berry has identified the following species:

Fossil plants from layer No. 2, Bolivar Creek section.

Ficus pseudomediafolia Berry.[1]
Juglans schimperi (Lesquereux)?
Palæodendron americanum Berry.[1]
Sapindus mississippiensis Berry.[1]
Sophora wilcoxiana Berry?

South of Bolivar Creek Crowleys Ridge rises about 115 feet (aneroid reading) above the bed of the creek; the ridge is here capped by brownish loam (loess), which rests upon a bed of gravel of the Lafayette formation.

[1] For description of this new species see Berry, E. W., The lower Eocene floras of southeastern North America: U. S. Geol. Survey Prof. Paper 91 (in press).

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At several places between Harrisburg and Bolivar Creek sands and argillaceous sands, probably corresponding to layers Nos. 6, 7, 8, and 9, were observed in gullies near the base of the west-facing slope of the ridge.

CORRELATION.

Berry has identified species of fossil plants from three localities referable to the Wilcox formation; from two of the localities (one in Greene County, p. 58, and the other in Clay County, p. 58) he recognized the following nine species:

Fossil plants from the Wilcox formation in Clay and Greene counties.

Anemia eocenica Berry.[1]
Banksia tenuifolia Berry.[1]
Dryophyllum tennesseensis Berry.[1]
Nectandra lowei Berry.[1]
Aralia notata Lesquereux.
Cinnamomum postnewberryi Berry.[1]
Ficus eolignitica Berry.[1]
Ficus vaughani Berry.[1]
Pteris eolignitica Berry.[1]

Berry states that all but one of the species enumerated occur in the Wilcox formation of the eastern Gulf region, and that the excepted species is common to the Fort Union formation of the western interior. On the evidence of these plants he correlates the containing beds with the Wilcox formation.

From the third locality, on Bolivar Creek, 3½ miles north of Harrisburg, Poinsett County (p. 62), Berry recognized five species, which he states indicate that the containing bed belongs near the top of the Wilcox. He says:

> I have no comparative data to prove that these forms do not extend into the Claiborne; however, none of the species have ever been found in the Claiborne, and in fact only one or two of the 250 species elsewhere found in the Wilcox have ever been found in the Claiborne. From this I conclude that the Bolivar Creek locality belongs to the Wilcox; I do not believe there is any lower Claiborne in Crowleys Ridge.

Although the contact between the Wilcox formation and the overlying Claiborne formation was not discovered, it is assumed, on the evidence afforded by the fossil plants, that the former does not appear in surface outcrops farther south in Crowleys Ridge than Harrisburg, Poinsett County.

CLAIBORNE FORMATION.

GENERAL FEATURES.

Name.—In 1834[2] and again in 1835[3] Conrad described a stratum of sand containing a rich molluscan fauna, exposed in a bluff on

[1] For description of this new species see Berry, E. W., The lower Eocene floras of southeastern North America: U. S. Geol. Survey Prof. Paper 91 (in press).

[2] Conrad, T. A., Observations on the Tertiary and more recent formations of a portion of the Southern States: Acad. Nat. Sci. Philadelphia Jour., vol. 7, pp. 116–129, 1834.

[3] Eocene fossils of the Claiborne, with observations on this formation in the United States: Fossil shells of the Tertiary formations of North America, vol. 1, No. 3, pp. 29–36, 1835. (See Harris's republication of Conrad's "Fossil shells," 1893, pp. 75–84.)

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Alabama River, at the village of Claiborne, Monroe County, Ala. He referred to this bed as the "Claiborne deposits," and in a later publication as the "Claiborne sandstone"; the Eocene age of the fauna was recognized. Since the introduction of the name it has been applied by different investigators to deposits distributed geographically from North Carolina to the Rio Grande. By some the name has been given a broader and by others a more restricted application than the present accepted limits of the division.[1]

[1] The literature on the subject is voluminous and can only be enumerated, not reviewed, in this report.

Conrad, T. A., Observations on the Eocene formation and descriptions of 105 new species of that period from the vicinity of Vicksburg, Miss., with an appendix: Acad. Nat. Sci. Philadelphia Proc., vol. 3, pp. 280–281, 1846.

Conrad, T. A., Observations on the Eocene deposit of Jackson, Miss., with descriptions of 34 new species of shells and corals. Acad. Nat. Sci. Philadelphia Proc., vol. 7, 1854, 1855, pp. 257–263 (issued in 1856).

Hilgard, E. W., A report on the geology and agriculture of the State of Mississippi, pp. 123–128, 1860.

Hilgard, E. W., On the Tertiary formations of Mississippi and Alabama: Am. Jour. Sci., 2d ser., vol. 43, pp. 33–34, 1867.

Mell, P. H., jr., The Claiborne group and its remarkable fossils: Am. Inst. Min. Eng. Trans., vol. 8, pp. 304–313, 1880.

Heilprin, Angelo, On the relative ages and classification of the post-Eocene Tertiary deposits of the Atlantic slope: Acad. Nat. Sci. Philadelphia Proc., p. 184, 1882.

Heilprin, Angelo, The Tertiary geology of the eastern and southern United States: Acad. Nat. Sci. Philadelphia Jour., vol. 9, pp. 116, 120, 145–147, 1884.

Heilprin, Angelo, The Tertiary geology of the eastern and southern United States: Published by the author; p. 37, Philadelphia, 1884.

Meyer, Otto, The genealogy and the age of the species in the southern old Tertiary: Am. Jour. Sci., 3d ser., vol. 30, pp. 421–435, 1885.

Aldrich, T. H., Observations upon the Tertiary of Alabama: Am. Jour. Sci., 3d ser., vol. 30, pp. 300–308, 1885.

Smith, E. A., Remarks on a paper of Dr. Otto Meyer on Species in the southern old Tertiary: Am. Jour. Sci., 3d ser., vol. 30, pp. 270–275, 1885.

Langdon, D. W., Tertiary of Mississippi and Alabama: Am. Jour. Sci., 3d ser., vol. 31, pp. 202–209, 1886.

Aldrich, T. H., Notes on the distribution of Tertiary fossils in Alabama and Mississippi: Cincinnati Soc. Nat. Hist. Jour., vol. 8, pp. 256–257, 1886.

Aldrich, T. H., a preliminary report upon the Tertiary fossils of Alabama and Mississippi: Alabama Geol. Survey Bull. 1, pp. 44–49, 1886.

Smith, E. A., Summary of the lithological and stratigraphical features and subdivisions of the Tertiary of Alabama: Alabama Geol. Survey Bull. 1, Introduction, pp. 8–10, 1886.

Smith, E. A., and Johnson, L. C., On the Tertiary and Cretaceous strata of the Tuscaloosa, Tombigbee, and Alabama rivers: U. S. Geol. Survey Bull. 43, pp. 15–18, 25–34, 1887.

Langdon, D. W., Geological section along the Chattahoochee River from Columbus to Alum Bluff: Georgia Geol. Survey First Rept. Progress, 1891, pp. 96, 97.

Langdon, D. W., Variations in the Cretaceous and Tertiary strata of Alabama: Geol. Soc. America Bull., vol. 2, p. 588, 1891.

Clark, W. B., Correlation papers—Eocene: U. S. Geol. Survey Bull. 83, 173 pp., 1891.

Spencer, J. W., Geological report on southwest Georgia: Georgia Geol. Survey First Rept. Progress, pp. 51–53, 1891.

McGee, W J, The Lafayette formation: U. S. Geol. Survey Twelfth Ann. Rept., pt. 1, pp. 413–418, 1891.

Smith, E. A., Phosphates and marls of Alabama: Alabama Geol. Survey Bull. 2, pp. 53, 62, 1892.

Harris, G. D., The Tertiary geology of southern Arkansas: Arkansas Geol. Survey Ann. Rept. for 1892, vol. 2, pp. 87–187, 1894.

Smith, E. A., Langdon, D. W., and Johnson, L. C., On the geology of the Coastal Plain of Alabama: Alabama Geol. Survey Bull., pt. 1, pp. 17, 122–138, 232–235, 492, 494, 1894.

Vaughan, T. W., The stratigraphy of northwestern Louisiana: Am. Geologist, vol. 15, pp. 210–220, 1895.

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As at present understood the term Claiborne is applied to the strata included between the Wilcox formation below and the Jackson formation above. In the other States in which the deposits have been recognized they have been subdivided on lithologic grounds into formations, and the term Claiborne group has been used. In Crowleys Ridge, where the deposits have not been subdivided, the term Claiborne formation is applied to the entire division.

In Louisiana the Claiborne has been subdivided in ascending order into the St. Maurice formation, which is composed of calcareous and glauconitic deposits of marine origin, and the Yegua or "Cockfield" formation, which consists of lignite-bearing sands and clays. The leaf-bearing clay in Crowleys Ridge near Cherry Valley, Cross County, described on page 69, is correlated by Berry with the Yegua ("Cockfield") formation of the Claiborne group. No deposits corresponding in lithologic character to the St. Maurice formation have been observed in Crowleys Ridge stratigraphically below the leaf-bearing clay at Cherry Valley, and there is reason to believe that only the upper part of the Claiborne is represented in northeastern Arkansas.

Areal distribution.—In northeastern Arkansas the Claiborne formation outcrops in the base of Crowleys Ridge to a probable maximum height of 100 feet above the adjoining lowlands, from the vicinity of Harrisburg, Poinsett County, to the southern part of Cross County.

East of Mississippi River deposits of the Claiborne group outcrop in North Carolina and from South Carolina southwestward through Georgia, westward through Alabama, and northward through Mississippi. The group is represented in Tennessee and Kentucky by a part of the Lagrange formation, but it has not been accurately differentiated from the strata of Jackson and Wilcox age, which are extensively developed in the same area and are also included in the Lagrange formation.

Vaughan, T. W., A brief contribution to the geology and paleontology of northwestern Louisiana: U. S. Geol. Survey Bull. 142, p. 15, 1896.

Dall, W. H., A table of the North American Tertiary horizons, correlated with one another and with those of western Europe, with annotations: U. S. Geol. Survey Eighteenth Ann. Rept., pt. 2, pp. 342–343, 1898.

Harris, G. D., and Veatch, A. C., A preliminary report on the geology of Louisiana: Louisiana Geol. Survey, pt. 5, pp. 73–89, 1899.

Vaughan, T. W., The Eocene and lower Oligocene coral faunas of the United States: U. S. Geol. Survey Mon. 39, pp. 27–30, 1900.

Veatch, Otto, and Stephenson, L. W., Tertiary and Quaternary [Georgia]: Geol. Survey Georgia Bull. 26, pp. 235–296, 1911.

Vaughan, T. W., [Tertiary of] Texas, Louisiana, and Arkansas: U. S. Geol. Survey Prof. Paper 71, pp. 723–731, 1912.

Vaughan, T. W., [Eocene and Oligocene of] south Atlantic and eastern Gulf Coastal Plain and north end of Mississippi embayment: U. S. Geol. Survey Prof. Paper 71, pp. 731–739, 1912.

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In southern Arkansas the Claiborne is probably represented by a part of the undifferentiated Eocene mapped by Veatch,[1] and deposits of this age have been recognized from northern Louisiana southwestward to the Rio Grande.

Stratigraphic relations.—In Crowleys Ridge the Claiborne formation rests upon the Wilcox formation, and the relation, though not determined with certainty, is probably that of nonconformity. Fossil leaves of upper Wilcox age have been found at the base of Crowleys Ridge, on Bolivar Creek, 3½ miles north of Harrisburg (p. 62), and fossil leaves of upper Claiborne age (Yegua) occur at the base of the ridge near Cherry Valley, Cross County (p. 69). From considerations based upon the general structure of the Mississippi Embayment and the slight inclination of the strata composing the Eocene, it is believed highly improbable that the full thickness of the Claiborne group of Alabama and Mississippi can be represented in outcrops in Crowleys Ridge, between the two localities mentioned. It seems necessary to assume, therefore, that the lower part of the Claiborne is represented by an unconformity. In a letter to the senior author, Berry discusses this hypothetical unconformity as follows:

> With regard to the Claiborne unconformity, I am convinced that the later Claiborne transgresses far to the north of the earlier. I have St. Maurice [lower Claiborne] plants from southern Arkansas and Yegua ("Cockfield") [upper Claiborne] plants from northwestern Mississippi, and the general relations of the deposits demand an unconformity. In materials away from the open sea—that is in littoral sands and lenses of estuarine clay, unconformities would scarcely even be detectable unless the unconformable deposits were laid down at very different depths, and consequently were of different lithologic character.

The Claiborne formation is overlain toward the southern limit of its occurrence in Crowleys Ridge by the Jackson formation; the relation is believed to be that of conformity.

Throughout the greater part of its extent in Crowleys Ridge the formation is overlain unconformably by gravels and sands of the Lafayette formation. Disturbed materials of the Lafayette formation and of the overlying loess have found their way down the slopes by redeposition, creep, and landslide, and have blanketed the Claiborne strata which would otherwise appear at the surface continuously along the base of the ridge.

Lithologic character.—The formation in Crowleys Ridge consists of regularly and irregularly bedded, more or less lignitiferous sands and clays, with subordinate, thin, interstratified layers of lignite. The sands are for the most part fine in texture, are commonly mica-

[1] Veatch, A. C., Geology and underground water resources of northern Louisiana and southern Arkansas: U. S. Geol. Survey Prof. Paper 46, p. 40, 1906.

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ceous, and are light to dark in color. The clays are light drab to black and range in bedding from massive to thinly laminated, with fine micaceous sand partings; locally, as at Copperas Bluff, Cross County, they are strongly gypsiferous, the gypsum being present as crystals and presenting numerous clusters of acicular crystals.

Concretions of iron carbonate are common in the clays of the formation, and appear in many of the exposures in Cross County. Lignite is characteristic and occurs as comminuted particles or as larger fragments.

Strike, dip, and thickness.—The strike of the strata composing the Claiborne formation is inferred, from the general structure of the Gulf embayment, to be approximately northeast-southwest. The beds dip to the southeast at the rate of a few feet per mile. No accurate data are available for determining the thickness of the formation, but rough calculations based on the width of outcrop and an assumed dip of between 5 and 10 feet per mile, give a thickness of between 100 and 200 feet for the formation.

Physiographic expression.—The present surface features of Crowleys Ridge are determined mainly by the Lafayette formation and by the loess, which form the capping materials of the ridge. However, the existence of that part of the ridge underlain by the Claiborne formation is due to the resistance to erosion offered by the strata of this terrane, and particularly by the thicker beds of clay. In this respect the ridge may be said to be a topographic expression of the formation.

Paleontologic character.—Fossil leaves, poorly to fairly well preserved, have been collected from the formation at an exposure three-fourths of a mile southeast of Cherry Valley, Cross County; a list of the identified species is given on page 69. Comminuted particles and larger fragments of lignite are common in the formation throughout practically its whole thickness. At a few places thin layers and lenses of lignite have been observed. No remains of animals have been found in place in the formation; however, at an exposure 4 miles east of Wynne shark teeth and mouth plates were found loose in the bed of a gully.

LOCAL DETAILS.

The Claiborne formation is well exposed at many places in Crowleys Ridge in Poinsett and Cross counties. Call[1] has described numerous sections in detail. A few sections are given to show the general lithologic character of the formation.

[1] Call, R. E., The geology of Crowleys Ridge: Arkansas Geol. Survey Ann. Rept. for 1889, vol. 2, pp. 57–80, 1891.

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Spencer Creek, Cross County.—Call[1] described a section on Spencer Creek, in Crowleys Ridge, 1 mile north of Harrisburg, Cross County, which is here repeated in substance, as follows:

Section on Spencer Creek 1 mile north of Harrisburg, Cross County.

	Feet.
Pleistocene (loess):	
Humus, with considerable sand and a few scattered pebbles	1
Yellowish loesslike marl, indurated below, weathering into vertical cliffs. This layer becomes much redder below and has occasional seams of pebbles with a matrix of red sand. At the very bottom the clay is almost entirely replaced by coarse, brick-red sand	20
Eocene (Claiborne formation?):	
Horizontally stratified white sands, alternating with light slate-colored layers of plastic clay, the thickness of the clay varying from half an inch to 5 inches. The thicker layers of clay are laminated, the laminæ being separated by thin layers of a very fine white sand, though these finer sand partings are sometimes stained yellow by iron oxide. Below the first 5 feet these clay bands almost entirely disappear and the whole becomes a very fine white horizontally stratified sand. This member is remarkable for the regularity and horizontality of its stratification	13
Stratified bluish to drab clays, with abundant small fragments of lignite scattered throughout, though in places these particles are arranged in zones 2 to 3 inches thick. Near the bottom is a heavy deposit of siliceous iron ore, in places forming the floor of the creek and elsewhere jutting out as a ledge from the bank. The thickness of this iron clay-stone varies from 1 foot to 15 or 20 inches	23
	57

Call says also:

Farther down the creek and west of the road is a continuation of the above section which extends its general features nearly half a mile to the west. In this exposure the iron clay-stone is nodulous and is represented by very large segregations instead of by a bed. Lignite is much more abundant and the fragments are larger than at the first-mentioned locality, but they are arranged in an undulating zone throughout the whole section. At the top of the section, for 7 feet of the total thickness, which is 25 feet, the character of the soil clearly resembles the loess clays and, though it is somewhat more deeply colored and more clayey than usual, it probably represents that deposit.

Although no fossils were found in this section, the presence of iron ore in the lowest layer and the regularity of the bedding exhibited by the two lower layers are regarded as evidence of their Claiborne age.

Cherry Valley section, Cross County.—The following is a section exposed on a small creek, where it leaves Crowleys Ridge about three-

[1] Call, R. E., op. cit., pp. 78, 79.

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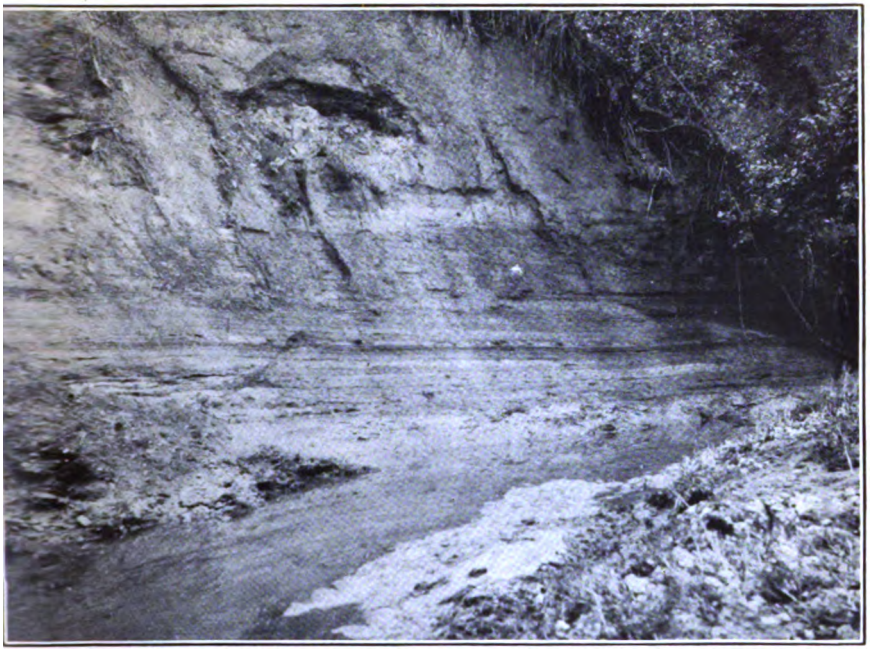
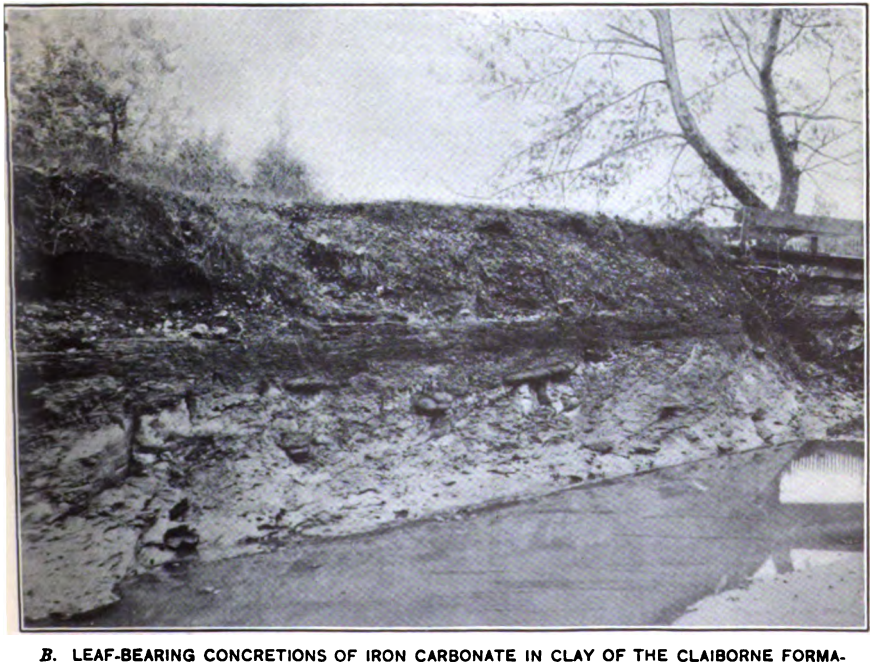


A. SANDS AND CLAYS OF THE CLAIBORNE FORMATION THREE-FOURTHS OF A MILE SOUTHEAST OF CHERRY VALLEY, CROSS COUNTY.



B. LEAF-BEARING CONCRETIONS OF IRON CARBONATE IN CLAY OF THE CLAIBORNE FORMATION AT THE LOWER END OF THE BLUFF SHOWN IN PLATE VI, *A*.

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quarters of a mile southeast of Cherry Valley, Cross County (see Plate VI, *A* and *B*):

Section near Cherry Valley, Cross County.

	Feet.
Pleistocene (loess):	
Brown pebbly loam, which has probably crept down the slope from a higher level	3
Pliocene(?) (Lafayette formation):	
Gravel composed of pebbles of angular to partially rounded gray and brown chert; a few scattered, smoothly rounded quartz pebbles, and a few scattered angular chunks of ferruginous conglomerate. The gravel mantles down over the slope and the whole bed has probably crept down the slope from a higher level	5
Unconformity.	
Eocene (Claiborne formation):	
Faintly laminated fine, rather compact argillaceous sand, red in the upper 5 or 6 feet and grading downward into light greenish-gray sand streaked with yellow; this is a weathered phase of the material described in the next layer below	
Brown, faintly laminated, finely micaceous argillaceous sand with crystals of selenite and scattered small particles of vegetable matter	14
Massive fine light greenish-gray sand streaked with yellow	12
Laminated dark-gray and dark-brown, very sandy micaceous clay, with laminæ and thin layers of gray, brown, and yellow fine sand having a maximum thickness of 2 or 3 inches; the bed contains comminuted vegetable particles and a few scattered fragments of lignite	8
Massive, finely arenaceous dark greenish gray clay, with numerous black fossil leaves preserved as lignite; scattered through the clay are numerous concretions of iron carbonate with a maximum diameter of 2 or 3 feet, which contain numerous fairly well preserved leaf impressions (Pl. VI, *A*, *B*); maximum exposed thickness	5
	47

From the leaf-bearing bed at the base of the section the following species, identified by E. W. Berry, were collected by Berry and the senior author:

Fossil plants near Cherry Valley, Cross County.

Arthrotaxis (?) sp.	Mimusops claibornensis Berry.[1]
Citrophyllum eocenicum Berry (occurs also at Claiborne, Ala.).[1]	Persea gratissimifolia Berry.[1]
Inga arkansensis Berry.[1]	Ternstrœmites crowleyensis Berry.[1]
	Ternstrœmites claibornensis Berry.[1]

[1] For description of this new species see Berry, E. W., The lower Eocene floras of southeastern North America: U. S. Geol. Survey Prof. Paper 91 (in press).

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On the evidence of the species enumerated, Berry correlates the containing stratum with the upper Claiborne, and states that the bed probably corresponds in age to the lignitiferous division of the Claiborne group of Louisiana and Texas known as the Yegua ("Cockfield") formation.

Sections east of Wynne, Cross County.—The following section is exposed in a ravine about 4 miles east of Wynne, Cross County, and one-fourth mile south of the St. Louis, Iron Mountain & Southern Railway:

Section in a ravine 4 miles east of Wynne, Cross County.

	Feet.
Pleistocene:	
Loess	18
Pliocene (?) (Lafayette formation):	
Gravel with a matrix of sand	18
Eocene (Claiborne formation):	
Light-gray argillaceous sand, irregularly streaked with yellow, pink, and red	6
Interbedded light-drab arenaceous clay and light-gray sand	15
Pink and yellowish mottled argillaceous sand	1
Very dark lignitic clay, with two thin seams of pure lignite	1.5
Gray and yellowish argillaceous sand	8
Concealed by a landslide	30
Dark-drab arenaceous lignitic clay, more sandy in its upper portion; contains crystals of selenite an inch or more in length; this layer is exposed along the bottom of the ravine below the landslide; a few shark teeth and mouth plates were found loose in the bed of the ravine	30
	127.5

In a bluff at the foot of the ridge near the mouth of the ravine 15 feet of dark clay, containing crystals of selenite and concretions of iron carbonate, some of which are a foot or more in diameter, is exposed.

Another clear-cut section in which strata of the Claiborne formation are exposed is a south-facing bluff on a small creek 3 miles east of Wynne and one-eighth mile north of the St. Louis, Iron Mountain & Southern Railway:

Section in a bluff on a small creek 3 miles east of Wynne and one-eighth mile north of the St. Louis, Iron Mountain & Southern Railway.

	Feet.
Pleistocene (loess):	
Massive grayish and brownish loess, with a reddish band (*a*, fig. 1) 5 or 6 feet thick extending horizontally through the middle portion of the layer	40
Light-gray compact argillaceous sand, with scattered small pebbles probably derived from layer 3 (fig. 1)	2–6

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	Feet.
Unconformity (?); a fairly sharp though not an absolutely sharp contact.	
Pliocene (?) (Lafayette formation):	
Gravel composed chiefly of subangular to partly rounded flint and chert pebbles and cobbles up to 5 or 6 inches in length, with a small percentage of smoothly rounded quartz pebbles up to 1 inch in length	0–5
Unconformity.	
Eocene (Claiborne formation):	
Dark-gray laminated compact shaly clay	5
Massive dark-gray to chocolate-tinted, very argillaceous sand, with numerous small particles of lignite; contains oval to spherical concretions of iron carbonate, which reach a maximum of 1 foot in diameter; small pieces of lignite form the nucleus of some of these concretions	7
	58

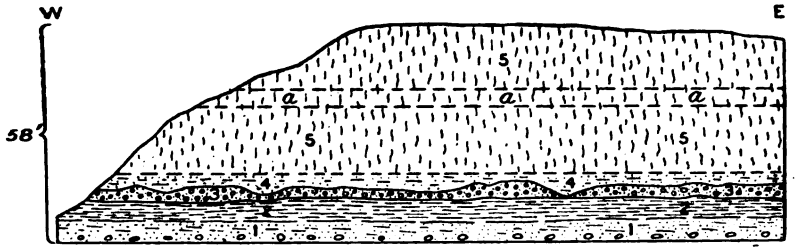

FIGURE 1.—Sketch to show the relations of formations exposed in a bluff on a small creek 3 miles east of Wynne, Cross County, and one-eighth mile north of the St. Louis, Iron Mountain & Southern Railway. 1 and 2, Claiborne formation; 3, Lafayette formation; 4, sandy layer at base of loess; 5, loess containing reddish band (a) near the middle.

The relations indicated in the section just described are graphically represented in figure 1.

Copperas Creek section, Cross County.—The site of Old Wittsburg is on St. Francis River, at the foot of the east-facing slope of Crowleys Ridge, about 5 miles east of Wynne, Cross County. Call[1] has described an exposure of the Claiborne formation on Copperas Creek north of Wittsburg. He says:

Two and a half miles north of Wittsburg Copperas Creek flows eastward from the ridge, and after a sinuous course through the alluvium of the St. Francis bottoms joins St. Francis River some distance to the south. Where it leaves the hills this stream has cut away the greater part of a north and south spur and exposed its stratigraphy.

[1] Call, R. E., op. cit., pp. 69–71.

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The section given by Call is in substance as follows:

Section at Copperas Bluff, Cross County.

	Feet.
Pleistocene (loess):	
Light-yellow siliceous humus	2
Loess with abundant concretions of calcium carbonate in the middle portion; the lower portion contains pebbles, which are particularly abundant near the base; weathers into vertical cliffs	5
Pliocene (?) (Lafayette formation):	
Gravel composed mainly of yellowish chert with an intermixture of varicolored sand; contains also pebbles of sandstone 3 to 4 inches in diameter; this bed is 1 foot thick at the extreme end of the section and thickens to a maximum of 8 feet at the west end of the section	5
Eocene (Claiborne formation):	
Reddish, partly indurated, cross-bedded, rather coarse sand, with numerous small pieces of light-yellow ocher disseminated in patches	5
Stratified drab to purplish sandy clay, with numerous fragments of lignite	15
Ironstone nodules, distributed somewhat regularly in a narrow zone; some of the nodules are hollow or are filled with sand	1
Bluish stratified clay, with an abundance of comminuted vegetable matter and some fragments of lignite; contains also many crystals of gypsum	10
Layer of ironstone concretions which forms a ledge along the face of the bluff	1
White and yellowish fine stratified sand; the layer thins out and disappears toward the west	10
Dark-bluish sandy stratified clay, with organic matter and numerous large fragments of lignite; contains much selenite, partly in the form of acicular crystals radiating from a common center	12
	66

CORRELATION.

The leaf-bearing clay exposed in the section near Cherry Valley, Cross County (p. 69), is the key to the correlation of this formation. According to Berry the fossil plants identified from this stratum indicate its upper Claiborne age and its probable synchronism with the Yegua ("Cockfield") formation of Louisiana and Texas. The Yegua formation is the upper lignitiferous division of the Claiborne group of those States. Fossil leaves of upper Wilcox age have been identified by Berry from a locality on Bolivar Creek, 3½ miles north of Harrisburg, Poinsett County (p. 62). He believes the paleontologic evidence strong that only the upper or Yegua ("Cockfield") formation of the Claiborne, as developed in southern Arkansas and in Louisiana, is represented in Crowleys Ridge (see p. 63), and that the Claiborne of this area must therefore be separated from the underlying Wilcox

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formation by an unconformity, corresponding in time to the lower Claiborne of other areas.

Fossil invertebrates of lower Jackson age have been identified by T. Wayland Vaughan from a marl bed exposed on Little Crow Creek about 3 miles east of Forrest City, St. Francis County (pp. 76–78).

With these paleontologic criteria as a check the areal distribution of the Claiborne formation in Crowleys Ridge, as indicated on the map, is determined on the evidence afforded by certain lithologic data, which, though not so satisfactory as paleontologic evidence, may nevertheless be considered valid.

Many of the sections in Cross County here referred to the Claiborne formation include beds of clay containing concretions of iron carbonate, and at the Cherry Valley locality, to which reference has just been made, these concretions are leaf-bearing. The fact that the concretions have not been found in the Eocene of Crowleys Ridge, either north or south of Cross County, seems to justify the opinion that they are characteristic of the Claiborne formation of this area.

The invertebrate-bearing beds on Crow Creek east of Forrest City in St. Francis County, which have been correlated with the lower Jackson, do not contain iron carbonate concretions, and this seems to be a further confirmation of the belief that the concretions are characteristic of the Claiborne formation.

JACKSON FORMATION.

GENERAL FEATURES.

Name.—Conrad[1] in 1856 described a series of calcareous, fossil-bearing clays typically exposed at Jackson, Miss., and applied to them the name Jackson. Subsequently, the deposits have been traced with certain interruptions from North Carolina to eastern Texas.[2]

Areal distribution.—In Arkansas the Jackson formation outcrops in the base of Crowleys Ridge to a probable maximum height of 100 feet above the level of the lowlands, from the northern part of

[1] Conrad, T. A., Acad. Nat. Sci. Philadelphia Proc., vol. 7, 1854–55, p. 257, 1856.

[2] The more important papers relating to the Jackson formation are listed below.

Hilgard, E. W., A report on the geology and agriculture of the State of Mississippi, pp. 128–135, 1860.

Hilgard, E. W., On the Tertiary formation of Mississippi and Alabama: Am. Jour. Sci., 2d ser., vol. 43, pp. 29–33, 1867.

Heilprin, Angelo, On the relative ages and classification of the post-Eocene Tertiary deposits of the Atlantic slope: Acad. Nat. Sci. Philadelphia Proc., p. 184, 1882.

Heilprin, Angelo, The Tertiary geology of the eastern and southern United States: Acad. Nat. Sci. Philadelphia Jour., vol. 9, pp. 116, 120, 145, 147–148, 1884.

Heilprin Angelo. The Tertiary geology of the eastern and southern United States, p. 87. Published by the author, Philadelphia, 1884.

Meyer, Otto, The genealogy and the age of the species in the southern old Tertiary: Am. Jour. Sci., 3d ser., vol. 30, pp. 421–435, 1885.

Aldrich, T. H., Observations upon the Tertiary of Alabama: Am. Jour. Sci., 3d ser., vol. 30, pp. 300–308, 1885.

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St. Francis County southward nearly to the southern extremity of the ridge in Phillips County. South of Arkansas River the terrane appears in Jefferson, Lincoln, Cleveland, Drew, and Bradley counties, Ark.

Stratigraphic relations.—In Crowleys Ridge the Jackson formation rests upon the Claiborne formation and is overlain unconformably by the Lafayette formation. The contact between the Jackson and Lafayette formations is very irregular, and varies in vertical position from near the level of the base of the ridge to at least 100 feet above that datum plane. The gravels and sands of the Lafayette formation and the loess that caps the ridge have found their way down the slopes by redeposition, creep, and landslides, and, except in ravines and stream bluffs, have almost completely blanketed the Jackson formation.

Lithologic character.—The Jackson formation in Crowleys Ridge consists of regularly and irregularly bedded, interstratified sands, clays, and fossiliferous marls of shallow-marine origin. Where the materials are unoxidized the colors range from light gray to dark greenish or bluish gray; where oxidation has taken place the materials are variegated with red, pink, yellow, and brown. The sands are massive to cross-bedded, vary in texture from fine to coarse, and

Aldrich, T. H., Notes on the distribution of Tertiary fossils in Alabama and Mississippi: Cincinnati Soc. Nat. Hist. Jour., vol. 8, pp. 256–257, 1886.

Smith, E. A., and Johnson, L. C., Tertiary and Cretaceous strata of the Tuscaloosa, Tombigbee, and Alabama rivers: U. S. Geol. Survey Bull. 43, pp. 19–25, 1887.

Langdon, D. W., Variations in the Cretaceous and Tertiary strata of Alabama: Geol. Soc. America Bull., vol. 2, p. 588, 1891.

Clark, W. B., Correlation papers; Eocene: U. S. Geol. Survey Bull. 83, pp. 68, 76, 1891.

Spencer, J. W., Geological report on southwest Georgia: Georgia Geol. Survey, First Rept. Progress, pp. 51–53, 1891.

McGee, W J, The Lafayette formation: U. S. Geol. Survey Twelfth Ann. Rept., pt. 1, pp. 412–413, 1891.

Smith, E. A., Phosphate and marls of Alabama: Alabama Geol. Survey Bull. 2, pp. 53–55, 1892.

Harris, G. D., The Tertiary geology of southern Arkansas: Arkansas Geol. Survey Ann. Rept. for 1892, vol. 2, pp. 87–176, 1894.

Smith, E. A., Langdon, D. W., and Johnson, L. C., On the geology of the Coastal Plain of Alabama, pp. 107–122, 376–385, Alabama Geol. Survey, 1894.

Vaughan, T. W., The stratigraphy of northwestern Louisiana: Am. Geologist, vol. 15, pp. 221–223, 1895.

Vaughan, T. W., A brief contribution to the geology and paleontology of northwestern Louisiana: U. S. Geol. Survey Bull. 142, p. 22, 1896.

Dall, W. H., A table of the North American Tertiary horizons, correlated with one another and with those of western Europe, with annotations: U. S. Geol. Survey Eighteenth Ann. Rept., pt. 2, p. 342, 1898.

Harris, G. D., and Veatch, A. C., A preliminary report on the geology of Louisiana: Louisiana Geol. Survey, pt. 5, pp. 89–93, 1899.

Vaughan, T. W., The Eocene and lower Oligocene coral faunas of the United States: U. S. Geol. Survey Mon. 39, p. 30, 1900.

Veatch, Otto, and Stephenson, L. W., Tertiary and Quaternary [Georgia]: Georgia Geol. Survey Bull. 26, pp. 296–306, 1911.

Vaughan, T. W., [Eocene and Oligocene of] Texas, Louisiana, and Arkansas: U. S. Geol. Survey Prof. Paper 71, pp. 727, 728, 1912.

Vaughan, T. W., [Eocene and Oligocene of] south Atlantic and eastern Gulf Coastal and north end of Mississippi embayment: U. S. Geol. Survey Prof. Paper 71, pp. 1912.

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in places contain small pebbles. The clays are massive to thinly stratified or laminated. The marls consist of calcareous and glauconitic sands or clays which in places, as on Little Crow Creek east of Forrest City, contain many fossil shells.

Particles and fragments of lignite are common in the formation and thin layers of lignite have been observed at a few places.

Strike, dip, and thickness.—From the general structure of the Coastal Plain in the Mississippi embayment it is believed that the strata composing the Jackson formation in Crowleys Ridge strike approximately northeast and southwest. From the data afforded by well records it is estimated that the beds dip to the southeastward at a rate which probably does not exceed 5 feet a mile.

The thickness of the formation has not been determined, but it probably does not exceed 200 feet in northeastern Arkansas.

Physiographic expression.—From Cross County southward to its southern extremity Crowleys Ridge, in so far as its existence is due to the resistance to erosion offered by the strata composing the Jackson formation, is a topographic expression of that formation. However, the present details of the surface have been determined largely by the Lafayette formation and the loess which form the capping materials of the ridge.

Paleontologic character.—The basal portion of the Jackson formation in Crowleys Ridge contains fossil mollusks ranging from poorly to well preserved. The most abundant species, *Ostrea alabamiensis* Lea, and the species *Modiola hamatoides* Call, together with some of the less common species, indicate that the containing materials were deposited in shallow marine waters. An abundant molluscan fauna is contained in the basal 22 feet of the section at White Bluff on Arkansas River, Jefferson County.

Lignite, in places segregated into thin beds, is common in the formation, and this also points to the shallow-water origin of the deposits.

Fossil mollusks and Foraminifera have been obtained from the Jackson formation in a well boring near Helena, Phillips County (see pp. 82, 83), and from well borings at Choctaw Bar, Desha County. Lists of fossils from the several localities mentioned are given on pages 78, 80, and 83.

LOCAL DETAILS.

From Cross County southward the east-facing slope of Crowleys Ridge is much steeper than the west-facing slope, a condition produced by the erosive action of St. Francis River, which at numerous places has cut against the foot of the ridge; the natural exposures which show the most complete sequence of strata are all in this steep, east-facing slope or in the deep ravines which cut the slope. A few of the more interesting sections and well logs are given in detail.

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Call[1] has given a large amount of detailed information concerning this part of Crowleys Ridge.

St. Francis County.—The most northerly observed exposure that is believed referable to the Jackson formation is in the eastern slope of the ridge 8 or 9 miles northeast of Forrest City, St. Francis County, and has been described by Call,[2] who says:

> A section studied in the SE. ¼ of the NW. ¼ sec. 29, T. 6 N., R. 4 [illegible] at a point where St. Francis River flows directly against the ridge and makes a sharp turn to the south, shows the sequence of strata from a height of 155 feet above it down to the river level. * * * For the greater part the section is nearly or quite vertical, and is mainly continuous from the loess top of the ridge to the Eocene clays at the water's level.

Call's section is in substance as follows:

Section on St. Francis River 8 or 9 miles northeast of Forrest City.

	Feet.
Pleistocene:	
Loess	60
Pliocene (?) (Lafayette formation in whole or in part):	
Sands and gravels with large masses of chert and some red pipe clay	40
Eocene (Jackson formation):	
Bluish or black stratified clays without fossils other than abundant small pieces of lignite	65
	165

The only natural exposure of the formation in Crowleys Ridge that has furnished important paleontologic data is a nearly vertical north-facing bluff on Little Crow Creek in St. Francis County, about a mile south of west of Madison, about one-eighth mile south of the Chicago, Rock Island & Pacific Railway, and about 3 miles east of Forest City. (See Pl. VII, *A* and *B*.) The section is as follows:

Section on Little Crow Creek near Madison, St. Francis County.

	Feet.
Pleistocene (loess):	
9. Gray massive loess which stands in a vertical cliff; grades downward into next layer	40
8. Dark-brown facies of loess, the so-called old soil zone; grades downward into next layer	3
7. Yellowish facies of loess; grades downward into next layer	7
6. Gray facies of loess, containing concretions of calcium carbonate; becomes light gray and sandy in lower portion and appears to grade downward into next layer; contains fossil shells, chiefly of land mollusks, in lower 10 feet (see list, p. 78)	15
5. Light-gray fine to medium grained argillaceous sand with subordinate lenses of gravel and scattered pebbles; locally ferruginous with numerous small limonite concretions	5

[1] Call, R. E., The geology of Crowleys Ridge: Arkansas Geol. Survey Ann. Rept. for 1889, vol. 2, pp. 36–57, 143–183, 1891.

[2] Idem, p. 56.

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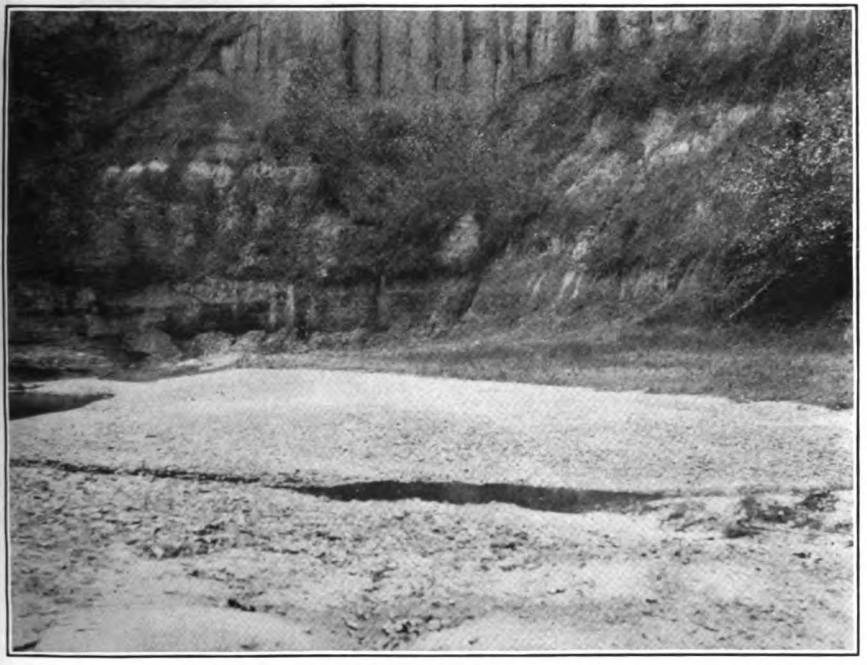
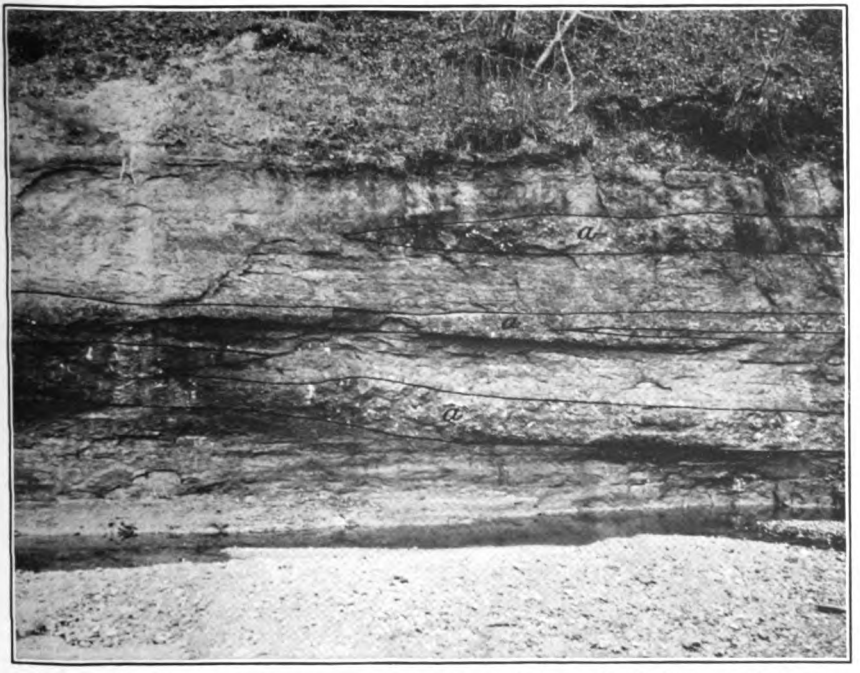


A. FOSSILIFEROUS CLAY OF THE JACKSON FORMATION OVERLAIN IN ASCENDING ORDER BY UNFOSSILIFEROUS SANDS AND CLAYS OF THE SAME FORMATION, THE LAFAYETTE FORMATION, AND THE LOESS, ON LITTLE CROW CREEK 3 MILES EAST OF FORREST CITY, ST. FRANCIS COUNTY.



B. NEAR VIEW OF THE BASE OF THE BLUFF ON LITTLE CROW CREEK SHOWN IN PLATE VII, *A*.

The successive positions of oyster beds as deposition continued are indicated by the black lines (*a*).

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	Feet.
The contact as exposed at several places is sharp and probably is an unconformity.	
Pliocene (?) (Lafayette formation):	
4. Heavy bed of gravel composed chiefly of brown and gray, angular to partially rounded pebbles of flint and chert up to 12 inches in length, with a small percentage of white, clear, or pink, smoothly rounded pebbles of quartz up to 1 inch in length; the pebbles and cobbles are in a matrix of coarse, gray, yellow, and brown sand	6
Unconformity.	
Eocene (Jackson formation):	
3. Fine gray sand with a few small lenses of light-drab clay	7
2. Light-drab laminated clay with seams and thin lenses of light-gray fine sand	7
1. Dark-gray compact laminated sandy clay with interbedded layers, lenses, and pockets of compact dark greenish gray argillaceous, slightly glauconitic sand; contains comminuted particles of lignite and scattered larger pieces of lignite; interbedded with the clay in the lower 15 feet are lenses and layers of large oysters (see Pl. VII, *B*, and fig. 2) with an admixture of other smaller forms; an oxidized zone extends along the upper 2 feet of the bed	20
	110

The accumulations of oysters in layer No. 1 (see Pl. VII, *B* (*a*), and fig. 2) mark the successive positions of the beds of living oysters which, as deposition continued, advanced and retreated in response to fluctuating favorable and unfavorable conditions.

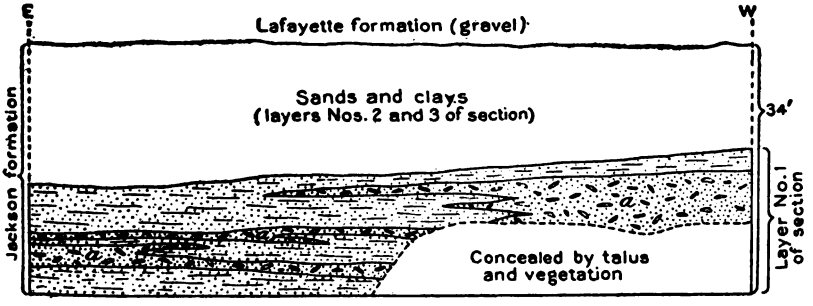

FIGURE 2.—Sketch to show the successive positions of oyster beds (*a*) as deposition continued, as revealed in the base of the bluff on Little Crow Creek, St. Francis County.

The marl bed, layer No. 1 of the section, was examined by Owen[1] as early as 1860 and was correlated by him with the Eocene.

In 1902 Harris[2] discussed the age of the marl and referred it provisionally to the Jackson formation.

[1] Owen, D. D., Second report of a geological reconnaissance of the middle and southern counties of Arkansas, pp. 412–420, 1860.

[2] See quotation on pp. 80–81 of this report.

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In 1895 T. Wayland Vaughan collected and identified the following species from layer No. 1:

Fossils from Little Crow Creek, St. Francis County.

Mazzalina inaurata Conrad.	Trinacria sp. (also at Claiborne).
Pseudoliva vetusta (Conrad).	Arca sp.
Buccinanops subglobosum (Conrad).	Ostrea alabamiensis Lea (abundant).
Odostomia sp.	Mytilus hamatoides Call.
Syrnola sp. 1.	Venericardia planicosta Lamarck.
Syrnola sp. 2.	Venericardia parva Lea.
Lunatia eminula (Conrad).	Cytherea discoidalis Conrad.
Turritella arenicola var. branneri Harris.	Lucina papyracea Lea.

Nearly all the species listed are common to the Claiborne and the Jackson. Both Harris and Vaughan are of the opinion that this marl corresponds in stratigraphic position to the marl exposed at the base of White Bluff, Arkansas River, which Harris has shown to be of Jackson age.

From the deep cut east of Forrest City eastward along Little Crow Creek toward Madison, in descending order, 2 or 3 feet of greenish sand, several feet of very lignitic clay, and several feet of gray stratified compact sand, which belong to the Jackson formation, are exposed in the bed of Little Crow Creek near the railroad track. A partially lignitized and partially silicified log, 2½ feet in diameter, was observed in the lignitic layer.

Phillips County.—Some of the numerous well borings in the vicinity of Helena throw light on the geology of the northeastern part of Phillips County. Logs of four such borings are given on pages 237–238. Especial attention is called to the log of the boring on Crowleys Ridge near Helena, made under the auspices of the Mississippi River Commission, and known as "boring No. 2, Helena."[1] Fossil mollusks taken from this well between the depths 171.3 and 231.3 feet were reported upon by Hilgard as follows:

> The fossiliferous clay and marl bed, 171.3 to 231.3 [feet], with its intercalated layer of bluish, impure limestone, is very distinctly characterized as Tertiary of the (marine) Claiborne group by the well-preserved specimens of the following shells: *Monoceros vetustas* Lea, *Actaeon lineatus* Lea, *Nucula magna* Lea. *Dentalium turritum* Lea, or *microstriatum* Heller, *Natica minima* Lea, *N. magnoumbilicata* Lea, *Pleurotoma lonsdalii* Lea; there is besides an undescribed Pleurotoma, Flabellum, and Retepora.

Concerning the correlation of these beds Hilgard further says:[2]

> Such as they are, however, these fossils overwhelmingly demonstrate the close correspondence of the beds penetrated at Helena and Choctaw Bar (whose

[1] Hilgard, E. W., U. S. Mississippi River Commission Ann. Rept. for 1883, Appendix T T of the Ann. Rept. of the Chief of Engineers for 1884, pp. 2892–2894. (Published also as House Ex. Doc. 37, 48th Cong., pp. 486–488, 1884.)

[2] Idem, p. 2886. (House Ex. Doc. 37, 48th Cong., p. 488, 1884.)

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facies is altogether identical) with the lower portion of the Claiborne beds of Alabama; perhaps most nearly with those older ones which Dr. Eugene A. Smith, State geologist of Alabama, has lately examined at and near Woods Bluff, Ala., and which rest directly upon the oldest lignitic and flatwoods clays.

Although Hilgard correlated the shell-bearing beds penetrated in the Helena boring with the lower Claiborne, Harris,[1] has shown that the strata are younger and belong to the Jackson formation.

This correlation accords with Vaughan's reference of the Crow Creek marl to the lower Jackson (p. 78), for from considerations based on the general structure of the Mississippi embayment it seems improbable that the marl penetrated in the Helena well should be stratigraphically lower than the marl on Little Crow Creek.

Arkansas River localities.—Outside of Crowleys Ridge the only surface occurrences of the Jackson formation in the area under immediate consideration are on Arkansas River in Jefferson County. The most noted locality is White Bluff, which has been described by Call[2] and by Harris.[3]

Harris says (p. 88):

In Volume II of the annual report of the Geological Survey of Arkansas for 1889, Prof. Call defines this locality as on the south side of Arkansas River, 3 S., 10 W., sec. 19, W. ½ of SW. ¼ and NW. ¼ of NW. ¼ of sec. 30. He gives a section consisting of 10 distinct beds aggregating 125 feet in thickness, which "was observed 400 feet west of a deep gulch which cuts through the entire section at right angles to the face of the bluff, directly opposite the house of J. Wallace at White Bluff Landing." The lower 40 feet of this section he found to be fossiliferous. * * *

This classic locality was visited by the writer on the 19th and 20th of November, 1891, when the waters of Arkansas River had been unusually low. Figure 16 * * * represents the bluff at the gulch referred to by Prof. Call.

Harris's description of the highest portion of the section figured by him is essentially as follows:

Section of White Bluff, Arkansas River, Jefferson County.

	Feet.
a. Light-colored sand	5–10
b. Line of chert pebbles	?
c. Soil and sand	8
d. Light-grayish sandy clay	9
e. Very light pink colored clay, containing numerous well-preserved dicotyledonous leaves	8
f. Similar to layer "*i*"	9
g. Dark lignitic clays, containing two bands of lignite, separated from the overlying bed by a seam of pure lignite from 3 to 6 inches thick	5–9
Unconformity.	

[1] See quotation on p. 83 of this report.
[2] Call, R. E., Arkansas Geol. Survey Ann. Rept. for 1889, vol. 2, pp. 7–9, 1891.
[3] Arkansas Geol. Survey Ann. Rept. for 1892, vol. 2, pp. 87–94, 1894.

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	Feet.
h. White sand, stained yellowish in places	4–8
i. Evenly laminated dark lignitic and more or less sulphurous shaly clay; between this bed and the former are occasional ferruginous concretions	11
j. Dark-bluish sandy marl, containing an abundant molluscan fauna in its lower portion	22

Harris says further (p. 91):

In tracing these various beds down the river from White Bluff, they were observed to be fairly persistent and to decline sufficiently in this direction to carry the lower bed *j* beneath the water within a distance of 1½ miles. Near the lower end of the bluff one feature is especially prominent, namely, the line of chert pebbles. Prof. Call, as remarked above, laid special stress on the singular absence of such pebbles in situ along this bluff; he probably did not visit this portion of the escarpment. A few hundred yards below the place represented in figure 16, huge angular blocks of bed *e*, or the leaf-bearing pinkish clay, have broken off and fallen to the base of the bluff. Vast quantities of leaf impressions were observed in them.

From the lowermost layer of the section, Harris identified the following species:

Ostrea sp.
Nucula magnifica Conrad (small).
Leda albirupina Harris.
Venericardia planicosta Lamarck.
Cytherea discoidalis Conrad.
Tellina sp.
Corbula nasuta Conrad var.
Mactra albirupina Harris.
Dentalium minutistratum Gabb.
Actæon pomilius Conrad.
Bullinella jacksonensis Harris var. exta.
Terebra sp.
Pleurotoma near P. lonsdalii Lea.
Pleurotoma near P. childreni Lea.
Cancellaria impressa Conrad.
Volutilithes petrosus Conrad.
Mitra millingtoni Conrad.
Pseudoliva vetusta Conrad.
Mazzalina inaurata Conrad.
Levifusus branneri Harris.
Fusus sp.
Phos albirupina Harris.
Turritella arenicola var. branneri Harris.
Turritella clevelandia Harris.
Solarium bellastriatum Conrad.
Natica eminula Conrad.

Discussing these fossils, Harris says:

The general aspect of this fauna is indeed Claibornian, as was suggested by Heilprin and maintained more confidently by Call.

Yet the presence of such forms as *Solarium bellastriatum*, *Mitra millingtoni*, and *Bullinella jacksonensis* var., show that the fauna is uppermost Claibornian or perhaps transitional between that and the Jackson. The most common fossils obtained at this locality are: *Venericardia planicosta*, *Turritella arenicola* var. *branneri*, *Mazzalina inaurata*, *Pseudoliva vetusta*, *Cytherea discoidalis*, and *Volutilithes petrosus*, all of which are found in Arkansas associated with typical Jackson fossils, as will be shown further on.

In 1892 Harris,[1] in discussing the Arkansas River localities, said:

At the time of writing my report on the Tertiary of Arkansas (1892), I felt strongly inclined to refer the fossiliferous beds at White Bluff, on Arkansas River, to the Jackson; yet they had always been referred to the Claiborne,

[1] Harris, G. D., The geology of the Mississippi embayment, with especial reference to the State of Louisiana: Louisiana Geol. Survey, pt. 6, p. 22, 1902.

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and there seemed not enough positive evidence in favor of the Jackson affinities to entirely warrant the change. Since then some of the new or supposedly new species from White Bluff have been found in abundance at Jackson, Miss., and at well-developed Jackson beds throughout Louisiana and east Texas. The Red Bluff beds, upstream a few miles from White Bluff, seem to be of the same horizon; and although I have not visited Crowleys Ridge personally, I feel quite confident, from Call's description of the beds and associated fossils, together with his correlations, that all should be placed in one and the same group. Accordingly the map of the Embayment area, as herewith published, shows the Jackson for the first time with its most probable northern distribution.

Call[1] describes a locality at Red Bluff, on Arkansas River, as follows:

There is an instructive section at Red Bluff, Jefferson County, in 3 S., 11 W., NE. ¼ of SE. ¼ sec. 12. At this locality there is exposed a section about five-eighths of a mile in length; the highest point, where the section was observed, is 276 feet above mean tide level. It is at the ferry, which is half a mile east of the western limit of the exposure. The section is best exhibited in a gully which enters the river at right angles to the face of the cliff. All the strata seen are horizontal.

Call's section is in substance as follows:

Section at Red Bluff, Arkansas River, Jefferson County.

	Feet.
Eocene (Jackson formation):	
Light-colored fine, very sandy humus, with scattered chert pebbles up to one-half inch in diameter	0.5
Soft light-yellow argillaceous sand, becoming darker below; contains numerous nodules of limonite	2.5
Dark carbonaceous earthy clay of varying thickness, less sandy than the overlying layer; resembles an old soil	.5
Irregularly stratified mottled sands and clays, light-yellow and brick-red predominating, with an occasional small pocket of white sand	4
Irregularly bedded sandstone forming a vertical and jutting face, thickest and hardest 100 feet west of the ferry; weathering on the upper surface, which occurred previous to the deposition of the overlying layer, is evidenced by potholes, ridges, etc.; the lower part of the sand is more regularly stratified than the upper part, and is of a brick-red color. Detached masses at the foot of the bluff contain pockets of pure white vitreous sand and very bright yellow and red potter's clay. Some of the layers of sandstone, especially the upper part, contain very hard tubes cemented with oxidized, manganiferous iron containing white sand	10.5
Soft yellow to reddish sand, with masses of bluish and yellowish potter's clay, becoming hard and intensely red at base	8

[1] Call, R. E., Arkansas Geol. Survey Ann. Rept. for 1889, vol. 2, pp. 10–13, 1891.

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Eocene (Jackson formation)—Continued.	Feet.
Fine dark to black, irregularly stratified, slightly sandy clay, with much selenite, chiefly in the form of star-shaped clusters, up to several inches in length	20
Dark-brown fossiliferous sandstone, with unidentifiable fossils; the cement of the sandstone is iron oxide; the layer forms a jutting ledge along the bluff	.5
Light-bluish, slightly sandy clay, containing numerous needle-like and stellate crystals of selenite, especially abundant toward the basal portion	23

Call says, further:

The Eocene Ostrea bed, or shell marl, which usually underlies this member of the Tertiary in all Arkansas outcrops, is to be seen at low water near the west end of this bluff. Close by the point of the above section a nodulous sandy marl similar to that at White Bluff and having the same fossils was observed, but its stratigraphic relations could not be determined because of the very heavy talus. It is thought that this marl bed is not quite horizontal in any portion of the region examined from the fact that it is seen at times rather high up in sections, and again it occurs only as lenticular masses in the bottom of streams and gullies. It is not a constant member of either this section or of that at White Bluff, appearing only at points in them.

Quotations from a paper by Gilbert D. Harris on the "Geology of the Mississippi embayment," which contains a discussion of the correlation of the White Bluff and Red Bluff sections, are given on pages 79–81.

CORRELATION.

The Eocene strata which outcrop in Crowleys Ridge from the northern part of St. Francis County southward nearly to the southern extremity of the ridge in Phillips County are correlated with the Jackson formation on the evidence of fossils obtained from an exposure of marl on Little Crow Creek, about 3 miles east of Forrest City, and from a boring at Helena. The Eocene age of the marl was recognized by Owen[1] as early as 1860.

The Jackson age of the bed was first suggested by Harris, whose discussion of the subject is given in a quotation on pages 80–81 of this report.

The first positive determination of the age of the marl on Little Crow Creek was that of T. Wayland Vaughan, who collected and identified the species listed on page 78; he correlates the bed with the marl at the base of White Bluff, which Harris has determined to be of Jackson age.

The fossils from the boring at Helena were first referred by Hilgard to the lower part of the Claiborne formation but were later shown by Harris to include characteristic Jackson species. Harris[2] says:

[1] Second report of a geological reconnaissance of the middle and southern counties of Arkansas, pp. 412–420, 1860.

[2] Geology of the Mississippi embayment: Louisiana Geol. Survey, pt. 6, pp. 22, 23, 1902.

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It should be mentioned in this place that we have had access to Hilgard's type specimens from Helena [from the boring just mentioned] and Choctaw Bar [from four borings], and have found that his specific determinations of molluscan fossils is not of the most satisfactory kind. The species are the same in general as at White Bluff, Ark., hence, as shown above, of Jackson age.

In a footnote Harris lists the following species from the borings at Helena and Choctaw Bar:

Helena, boring No. 2.

Dentalium (very nearly smooth but with traces of longitudinal striation).
Volutilithes petrosus Conrad (fragments).
Corbula wailesiana Harris.
Corbula sp.
Phos hilli Harris (var.).
Pseudoliva vetusta (Conrad).
Pleurotoma denticula Basterot.
Actæon sp.
Natica sp.

Choctaw Bar, boring No. 1.

Venericardia planicosta Lamarck.
Dentalium (as at Helena).
Cadulus sp.
Pleurotoma sp.
Actæon sp.
Turritella (very small, unicarinate at base).
Phos hilli Harris.

Choctaw Bar, boring No. 2.

Phos hilli Harris.
Natica (small).
Pleurotoma infans Meyer.
Levifusus trabeatus Harris.
Cancellaria sp.
Corbula (small), probably C. wailesiana Harris.
Turritella clevelandia Harris.
Venericardia rotunda Lea.
Volutilithes petrosus Conrad.
Actæon sp.
Calyptraphorus velatus Conrad (tip).

Choctaw Bar, boring No. 4.

Turritella (small, sharply bi-carinate).
Phos hilli Harris.
Oliva cf. O. gracilis Lea.
Natica (small).
Venericardia parva Lea.
Corbula wailesiana Harris.

Choctaw Bar, boring No. 5.

Pseudoliva vetusta (Conrad).
Natica (small).
Pleurotoma denticula Basterot.
Venericardia planicosta Lamarck.
Turritella (tip, bicarinate).
Volutilithes petrosus Conrad.
Corbula wailesiana Harris.
Actæon sp.

The borings at Helena and Choctaw Bar were described by Hilgard[1] in 1884. The log of boring No. 2 at Helena is given on page 238 of this report. Choctaw Bar is a few miles above Arkansas City in Desha County, Ark. The fossils from the borings at this place were taken at depths between 151 and 185.2 feet.

The total thickness of Eocene strata overlying the marl exposed on Little Crow Creek and penetrated in the boring at Helena probably does not exceed 200 feet. The thickness of the Jackson formation in Mississippi has been estimated to be between 350 and 450 feet, and if this is a correct estimate it seems reasonable to assume

[1] U. S. Mississippi River Commission Ann. Rept. for 1883; Appendix T T of the Ann. Rept. of the Chief of Engineers for 1884, pp. 2891–2896 (published 1884). (Published also as House Ex. Doc. 37, 48th Cong., pp. 486–490, 1884.)

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that the 100 feet or less of strata which overlie the marl bed of lower Jackson age in Crowleys Ridge in St. Francis, Lee, and Phillips counties is referable to the Jackson formation. Strata of Jackson age probably underlie the alluvium of Mississippi River valley from Helena, Phillips County, to Arkansas City, Desha County.

UNDIFFERENTIATED EOCENE.

Undifferentiated strata of Eocene age outcrop in the upland southwest of Arkansas River, in Pulaski, Sabine, Grant, and Jefferson counties. These are described by Veatch[1] as consisting of "lignitiferous clays and sands, containing no distinctive marine fossils."

In the northwestern part of Lonoke County, east of Cabot and south of Austin, is a hilly tract of country rising 100 to 125 feet above the level of the Advance lowland, or 350 to 375 feet above sea level; the exact limits of the area have not been determined, but the north-south extent is believed to be 10 or 12 miles and the east-west extent 5 or 6 miles. These hills appear to be composed mainly of coarse reddish ferruginous sand, with subordinate lenses and layers of drab clay, reaching a thickness of 100 feet or more. The weathered sands form the main constituent of the soils, and the clays are exposed at numerous places along the roads and in fields. These strata overlie deposits of undoubted Midway age and are believed to belong to the Eocene, though they are as yet undifferentiated. (See geologic map, Pl. II, p. 30.)

The following section is poorly exposed in the ditches of the public road one-half mile south of the station at Austin:

Section in public road one-half mile south of the station at Austin, Lonoke County.

Eocene:	Feet.
3. Reddish, ferruginous, coarse sand with occasional lenses of drab clay, and toward the base containing mechanically included clay balls; the materials are poorly exposed and much weathered	40
2. Drab weathered clay	5
1. Massive, weathered, glauconitic sand; the glauconite grains are partially weathered to brown	4
	49

In the Advance lowland west of Crowleys Ridge and the Mississippi lowland east of Crowleys Ridge stratified sands, clays, and marls of Eocene age, underlie 100 to 225 feet of alluvial material, and dip away from the rim of the Mississippi embayment at the rate of a few feet a mile. The Eocene deposits probably reach a maximum thickness of 1,000 to 1,200 feet or more within the area under consideration, and they rest upon deposits of Cretaceous age.

[1] Veatch, A. C., Geology and underground water resources of northern Louisiana and southern Arkansas: U. S. Geol. Survey Prof. Paper 46, p. 40, 1906.

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The buried Eocene deposits probably represent, in ascending order, the Midway, Wilcox, Claiborne, and Jackson formations. Although a number of well borings have penetrated the deposits, data sufficient for differentiating the several formations named have not been obtained. However, considerations of structure make it possible in some places to determine with a fair degree of certainty the formation to which the water-bearing beds belong.

PLIOCENE SERIES.

LAFAYETTE FORMATION.

GENERAL FEATURES.

Name.—The name Lafayette is derived from Lafayette County, Miss., where materials once regarded as typical of the formation to which the name was intended to apply are exposed in railroad cuts and natural sections, particularly in the vicinity of Oxford. The history of the events leading up to the adoption of the name has been given by McGee.[1] As recent investigations have shown that the so-called Lafayette formation includes geologic deposits ranging in age from Cretaceous to Pleistocene, and as the deposits at the type locality are of Wilcox Eocene age, the name is unsatisfactory. It is tentatively used in this paper, pending consideration now being given to the complex of constituents included in the formation.

In certain parts of the Mississippi embayment, including parts of Mississippi, Tennessee, Kentucky, and Illinois east of Mississippi River, and Missouri and Arkansas west of that stream, are upland deposits of gravel and sand, to which the term "Orange sands" was applied previous to the adoption of the name Lafayette and which the name Lafayette was intended to cover. In this connection it should be stated that Safford,[2] who in 1856 introduced the term "Orange sand," did not clearly distinguish between the gravels and sands of later geologic age and the underlying Eocene sands and clays, although he seems never to have fully concurred with Hilgard, McGee, and others in regarding his Orange sand as a distinct surficial formation. Other subsequent investigators in Tennessee and Mississippi failed to make the same distinction. At a conference[3] held in San Francisco in 1891, and participated in by McGee, Hilgard, Loughridge, and LeConte, it was decided that the name Lafayette should supplant the name "Orange sands," and the beds exposed at Oxford, Lafayette County, were chosen as the type locality of the formation.

[1] McGee, W J, The Lafayette formation: U. S. Geol. Survey Twelfth Ann. Rept., pt. 1, pp. 498–502, 1891.

[2] Safford, J. M., A geological reconnaissance of the State of Tennessee, p. 162, 1856.

[3] U. S. Geol. Survey Twelfth Ann. Rept., pt. 1, pp. 500–501, 1891.

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On the evidence of fossil plants Berry[1] has recently shown that the so-called type exposures of the Lafayette formation at Oxford are of Eocene age and referable to the Wilcox formation; the name, therefore, was unfortunately chosen. It is now demonstrated that gravel deposits similar to those referred to the Lafayette formation occur as terraces and valley fillings along the principal streams of the Coastal Plain and represent geologic formations of several different ages. The differentiation, characterization, and correlation of the terraces and associated fluvial phenomena are in progress, but the studies are not sufficiently advanced to correlate with confidence the phenomena of one area with those of another. Therefore the designation of certain gravel deposits in Tennessee, Kentucky, southern Illinois, and northeastern Arkansas as Lafayette is only provisional, for the gravels designated Lafayette in this report may subsequently be shown to be in part of Pleistocene age.

The distribution and character of the Lafayette formation in the Mississippi embayment east of Mississippi River have been treated by Crider[2] and Glenn,[3] the former with reference to Mississippi and the latter with reference to Tennessee, Kentucky, and southern Illinois.

Areal distribution.—The Lafayette formation is present in Crowleys Ridge throughout its entire extent from Stoddard County, Mo., to Phillips County, Ark. East of Mississippi River it is broadly developed over the northwestern part of Mississippi, the western parts of Tennessee and Kentucky, and the southern part of Illinois, where it rests upon Eocene and Cretaceous strata and laps over upon the Paleozoic rocks. Its detailed distribution in these States has, however, not been determined, and the formation is known to be absent in certain areas where it has heretofore been supposed to exist.

The formation is represented along the western margin of the Mississippi embayment in Arkansas by scattered deposits of gravel and sand which overlie the Eocene deposits in the Grandglaise terrace and occupy the east-facing slopes of the hills of the Ozark province; their distribution has not been determined in detail.

Stratigraphic relations.—In Crowleys Ridge the formation rests with a marked unconformity upon the beveled edges of the Wilcox, Claiborne, and Jackson formations; the contact varies in vertical position from near or a few feet above the level of the Mississippi lowland to 100 feet or more above that datum. Owing to disturbances in the nature of creep, landslides, and redeposition to which the ma-

[1] Berry, E. W., The age of the type exposures of the Lafayette formation: Jour. Geology, vol. 19, pp. 249–256, 1911.

[2] Crider, A. F., Geology and mineral resources of Mississippi: U. S. Geol. Survey Bull. 283, pp. 44–46, 1906.

[3] Glenn, L. C., Underground waters of Tennessee and Kentucky west of Tennessee River and of an adjacent area in southern Illinois: U. S. Geol. Survey Water-Supply Paper 164, pp. 40–43, 1906.

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terials have been subjected, it is difficult at many places to determine whether or not they are in their original place of deposition, and this fact has led to some confusion as to the stratigraphic relations of the deposits. However, there is abundant evidence to show that the deposits were laid down upon a strongly eroded surface.

In Crowleys Ridge the formation is overlain by deposits of loess of Pleistocene age and the relation between the two formations is believed to be that of nonconformity; this determination is based on sections examined east of Wynne, in Cross County (pp. 71, 92, 109); east of Forrest City, in St. Francis County (pp. 76, 93); and north of Helena, in Phillips County (pp. 94, 95), where unconformities more or less clearly defined have been noted. At some of the exposures in Crowleys Ridge, however, the contact between the two classes of deposits is not clearly defined. This interpretation is in substantial agreement with the conclusions of other investigators in adjacent areas. With reference to the attitude of the two formations in southern Illinois, Chamberlin and Salisbury[1] say:

> The erosion slopes of the hills, cut out of the horizontally though irregularly stratified sands and gravels, are thus seen to be strewn with gravel, sandstone débris, and ferruginous concretions, originating from the same series higher on the slope. Overspreading the whole, covering the crests of the hills and the eroded edges of the sand and gravel layers, together with their thin covering of local débris, as above indicated, is the mantle of loess. It is absent only where recent erosion has been sufficient to effect its removal. How far the uniformity of distribution of loess over regions of strongly accentuated relief may be due to the creep of the plastic material down the slopes, is not here discussed; but this is not believed to be an adequate explanation of its uniform slope distribution. The loess and its clayey equivalents are confidently believed to have been deposited like a mantle over a previously eroded surface. If the body of the hills be Paleozoic rock with only a capping of gravel and sand the relation of the loess to the latter is not altered.

In a discussion of the relation of the Pleistocene deposits to the underlying Lafayette formation in the Mississippi embayment east of Mississippi River Glenn[2] says:

> At some places along the Mississippi bluffs and in a belt 10 to 20 miles wide east of the bluffs the loess seems to rest unconformably directly on the Lafayette sands or gravels. At other places, however, there is a distinctly differentiated bed of soft, loose, light-colored sand between the two. This sand often contains rounded pebbles similar to those of the Lafayette beneath, from which they have evidently been derived. Like the sand, which may also have originated from the Lafayette, the pebbles are usually bleached to a light gray. This difference in color and the softness of the sand serve to differentiate the deposit at once from the red, case-hardened Lafayette beneath. This sand

[1] Chamberlin, T. C., and Salisbury, R. D., On the relationship of the Pleistocene to the pre-Pleistocene formations of the Mississippi basin south of the limit of glaciation: Am. Jour. Sci., 3d ser., vol. 41, pp. 367, 368, 1891.

[2] Glenn, L. C., Underground waters of Tennessee and Kentucky west of Tennessee River and of an adjacent area in Illinois: U. S. Geol. Survey Water-Supply Paper 164, p. 44, 1906.

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may range in thickness up usually to 4 or 5, and exceptionally to 10 or 12 feet, and may attain its maximum and disappear again in 100 or 200 yards.

It [the sand] commonly though not everywhere shows distinct unconformity on the Lafayette beneath and as a rule seems to grade upward into the lower, darker part of the loess without any perceptible break. Where the sand seems to be absent the lowest part of the loess is usually somewhat sandy, and may contain a small pebble here and there for several feet upward from its base. It is likely that in such cases the sandy basal part of the loess is the representative of the sand found elsewhere.

From the last quotation given it would appear that in Tennessee and Kentucky the loess, or the thin bed of soft sand which in places occurs at the base of the loess, rests unconformably upon the Lafayette formation.

Locally, on the higher parts of Crowleys Ridge north of Craighead County the loess has been eroded away leaving the gravels capping the tops of the hills.

Lithologic character.—The Lafayette formation in Crowleys Ridge is composed of irregularly bedded gravels and coarse sands. In general heavy beds of gravel occupy the base of the formation and consist mainly of subangular to partly waterworn pebbles and cobbles of chert, the latter rarely exceeding a foot in longest dimension. (See Pl. VIII, *A*.) The pebbles and cobbles were derived from the cherty limestones of the Ozark province, as indicated by the contained fossils of Paleozoic age. In places fragments of sandstone and quartzite, more or less waterworn, are mixed through the gravels; these fragments were derived in part from the quartzites of the Wilcox formation exposed in the northern part of Crowleys Ridge, and in part from the Paleozoic rocks of the Ozark province. At most of the exposures of gravel occasional small, smooth, waterworn pebbles of quartz may be found. (See p. 99.)

At some of the exposures revealing the thicker parts of the formation the basal gravels are overlain by coarse cross-bedded sands with numerous lenses and layers of gravel of greater or less extent; locally thin layers of laminated clay have been noted in the sands. At some places the gravels and sands are intermixed with lumps of mechanically derived clay.

Both the sands and gravels are varicolored and have been strongly oxidized. At many places the basal gravels have been cemented by iron oxide into a hard, ferruginous conglomerate, and at a few places the sands have been observed partially indurated to red sandstones. These indurated masses have formed where percolating waters carrying iron oxide in solution have had their downward circulation checked by compact layers of clay or other impervious materials.

Thickness.—The Lafayette formation in Crowleys Ridge ranges in thickness from a few feet to a maximum observed thickness of 80 feet. The difference in thickness at different places is due in part

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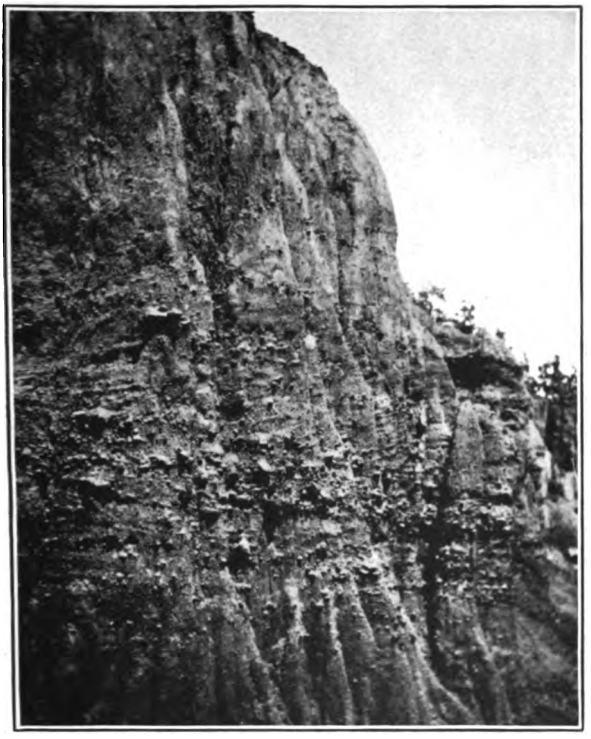
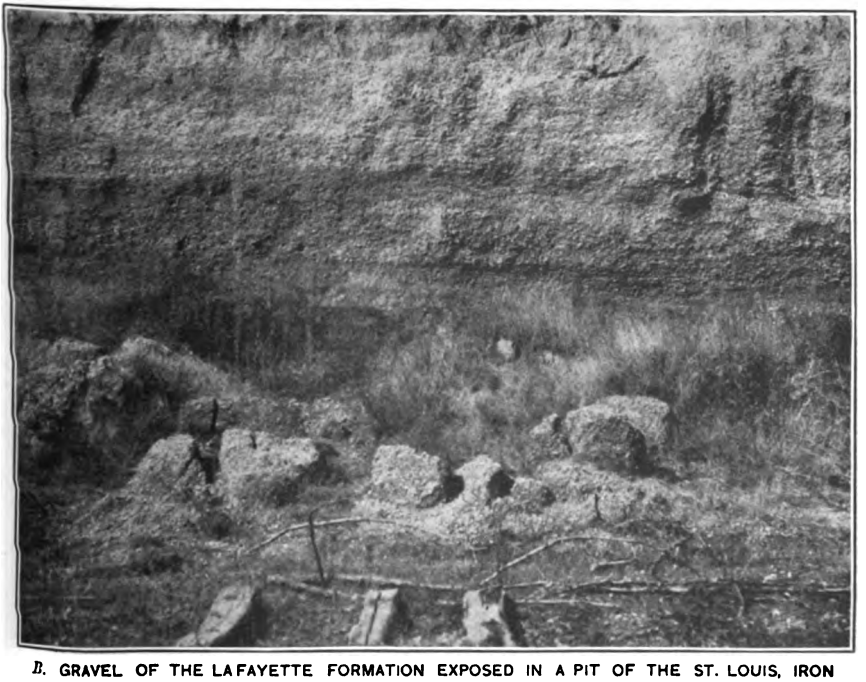


A. GRAVEL OF THE LAFAYETTE FORMATION EXPOSED IN THE WEST SLOPE OF CROWLEYS RIDGE NEAR COLT, ST. FRANCIS COUNTY.



B. GRAVEL OF THE LAFAYETTE FORMATION EXPOSED IN A PIT OF THE ST. LOUIS, IRON MOUNTAIN & SOUTHERN RAILWAY 2 MILES WEST OF NEWARK, INDEPENDENCE COUNTY.

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to the unconformable relations of the formation to the underlying Eocene deposits, in part to the variable amounts of materials deposited at different places and in part to the erosion which followed the deposition of the materials. The maximum observed thickness of the formation (80 feet) in Crowleys Ridge is in the section at the Big Spring, 2½ miles north of Helena, Phillips County.

Physiographic expression.—In so far as Crowleys Ridge is composed of the materials of the Lafayette formation the ridge is a topographic expression of the formation. The outcropping beds of gravel have determined in part the detailed topographic features of the slopes of the ridge. From Craighead County northward the loess has been removed from the top of the ridge at numerous places by erosion, leaving the gravels as the capping materials; at such places the resistance to erosion offered by the gravels is checking what would otherwise be a rapid reduction in the height of the ridge.

LOCAL DETAILS.

Gravels and sands of the Lafayette formation are exposed at many places in Crowleys Ridge throughout its length, from Stoddard County, Mo., to Phillips County, Ark. Detailed descriptions of many localities have been given by Call,[1] who, however, did not clearly differentiate this formation from the underlying Eocene sands, which, with the sands and gravels of the Lafayette formation, he included in the so-called "Orange sands."

At most places in Crowleys Ridge the basal part of the Lafayette formation consists of a heavy bed of gravel which rests with a marked unconformity upon the underlying Eocene sands or clays, and, with local exceptions, no difficulty is found in determining the contact between the deposits of the two ages.

Deposits of sand and gravel in the form of erosion remnants occur at many places along the western border of the Mississippi embayment, some forming a part of the Grandglaise terrace and others resting upon the Paleozoic rocks of the Ozark province.

A few typical sections will be described in this report.

Clay County.—According to Call[2] (p. 57 of this report) the summit of the ridge at Chalk Bluff, on St. Francis River, in the northern part of Clay County, is capped with fine gravels and coarse sands.

Southwest of Chalk Bluff, in Clay County, the gravels have been observed at numerous places on the crest and on the slopes of Crowleys Ridge. Where they occur on the divide they are covered with a few feet of loess, except locally, where the latter has been removed by erosion.

[1] Call, R. E., The geology of Crowleys Ridge: Arkansas Geol. Survey Ann. Rept. for 1889, vol. 2, pp. 30–142, 1891.

[2] Idem, pp. 114, 115.

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On the Boydsville-Gainesville road, 2 or 2½ miles southwest of Boydsville, a bed of indurated gravel cemented with iron oxide forms a hard, ferruginous conglomerate capping the divide of the ridge.

The loess of Clay County is nearly everywhere underlain by coarse dark red sands, in places pebbly, which appear to grade upward into the more typical loess. Whether this sand belongs to the Lafayette formation or should be considered a sandy phase of the loess was not determined.

Greene County.—Exposures of the formation are numerous in Greene County. A section exposed in a public road one-eighth of a mile west of Gainesville is as follows:

Section in public road one-eighth of a mile west of Gainesville.

	Feet.
Pleistocene (loess):	
Light-colored loam	4
Red loamy clay	2
Pliocene(?) (Lafayette formation):	
Gravel consisting of pebbles of chert of different colors, brown predominating, up to 5 inches in longest diameter, with an intermixture of small, smoothly waterworn pink and white quartz pebbles; locally indurated to a ferruginous conglomerate	.5
Coarse red, somewhat argillaceous sand	6
	12.5

Three and one-half miles west of Gainesville the road leading to Beech Grove crosses a ridge 200 feet higher than the lowland to the west (aneroid reading); 30 feet below the top of the ridge a bed of gravel is poorly exposed in the slope and is overlain by a red phase of loess.

From 4 to 7 miles west of Paragould where a public road crosses the highest part of the ridge (475 to 500 feet above sea level) are beds of gravel not exceeding an observed thickness of 5 feet, overlain, except locally, by 1 to 5 feet of brownish or reddish loam (loess). The gravels consist chiefly of gray, brown, and pink subangular to fairly well rounded pebbles of flint and chert up to 6 inches in length, with a considerable percentage of white, partially rounded to smoothly rounded pebbles of quartz up to 1 inch in length.

An exposure on Poplar Creek, NW. ¼ sec. 10, T. 16 N., R. 4 E., which reveals 30 feet of materials referable to this formation, has been described by Call.[1] This section is given on page 60 of this report.

[1] Call, R. E., op. cit., p. 111.

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Craighead County.—An exposure in a gully on the old William Lane place, 4 miles northeast of Bono, Craighead County, sec. 9, T. 15 N., R. 3 E., which shows the relation of the Lafayette formation to the underlying Wilcox formation and to the overlying loess, is described on page 61.

One of the best exposures of the formation in Crowleys Ridge is on the farm of Mrs. Mahala Shelton, 6 miles southwest of Jonesboro, on the south side of one of the small headwater streams of L'Anguille River. The section is about 200 feet long and 45 to 50 feet high; the base of the section in the bed of the stream is a few feet lower than the level of the lowland to the west.

Section on the Shelton farm, 6 miles southwest of Jonesboro.

	Feet.
Pleistocene:	
Loess mixed with pebbles, with a thin layer of pebbles along the base (varies in thickness along the bluff from 2 to 6 feet); this material has probably all crept down the slope from a higher level, which explains the unconformable relation of the loess to the underlying Lafayette formation at this locality	4
Unconformity.	
Pliocene ? (Lafayette formation):	
Coarse, red sand grading downward into coarse gray sand, the whole crossbedded (varies in thickness along the bluff from 6 to 10 feet)	10
Pebbles and sand intermixed, containing lumps of white plastic clay	4
Coarse, strongly crossbedded, pink-tinted sand, forming as a whole a nearly horizontal bed	13
Sand and gravel interstratified	4
Massive to cross-bedded gravel consisting mainly of subangular to partly waterworn brown chert pebbles and cobbles, reaching a maximum dimension of 1 foot; red, pink, gray, and black chert pebbles were also observed; a few small, smoothly waterworn pink and white quartz pebbles occur mixed with the chert. The thickness varies along the bluff from 4 to 11 feet	11
Unconformity.	
Eocene (Wilcox formation):	
Coarse white to yellow cross-bedded sand (varies in thickness along the bluff from 4 to 11 feet)	4
	50

Poinsett County.—Gravels of the Lafayette formation are poorly exposed on the west-facing slope of Crowleys Ridge at Harrisburg, Poinsett County. The main bed crops out on the crest of the steep part of the slope about 75 feet above the level of the Advance lowland, and talus gravels occur at numerous places below the crest.

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Although no clear-cut exposure was observed, the gravel bed probably exceeds 10 feet in thickness in the vicinity of the town. The gravels consist predominantly of brown, partially rounded to smoothly rounded pebbles of flint and chert, up to 1 foot in length, and some of them contain impressions of Paleozoic crinoids; a few of the chert pebbles are gray, pink, and red tinted. A noticeable proportion of the gravels consists of white, pink, and clear, partly rounded to smoothly rounded pebbles of quartz up to 1½ inches in length. The gravels in the vicinity of Harrisburg are overlain by loess which, on the higher parts of the ridge east of the town, probably reaches a maximum thickness of 25 feet or more.

Beds of gravel similar to those at Harrisburg occur on Crowleys Ridge practically throughout its length in Poinsett County. Call[1] has described several localities and has recorded a maximum observed thickness of 40 feet of deposits referable to the formation.

Cross County.—Five feet of gravel of the Lafayette formation is exposed above the Claiborne formation in the section near Cherry Valley, Cross County, described on page 69.

Near the west end of a cut of the St. Louis, Iron Mountain & Southern Railway, 1 mile east of Wynne, the formation is seen in relation to the underlying Claiborne formation and to the overlying loess.

Section in an excavation for road metal 1 mile east of Wynne, near the west edge of Crowleys Ridge and just south of the St. Louis, Iron Mountain & Southern Railway.

	Feet.
Pleistocene (loess):	
3. Gray loess grading downward into brown coarse sandy loess at base; scattered pebbles present in the lower 2 or 3 feet	10
Contact fairly sharp and undulates 2 or 3 feet in a distance of a few rods.	
Pliocene(?) (Lafayette formation):	
2. Coarse gravel, consisting chiefly of subangular to fairly well rounded pebbles and cobbles of brown and gray flint and chert up to 6 inches in length, with a small percentage of smoothly rounded, white, pink-tinted, and clear quartz pebbles up to 1 inch in length; the pebbles and cobbles are in a matrix of coarse, reddish sand; a few inches to 1 foot of the basal portion of the bed is indurated to a hard ferruginous conglomerate	16
Unconformity.	

[1] Call, R. E., The geology of Crowleys Ridge: Arkansas Geol. Survey Ann. Rept. for 1889, vol. 2, pp. 77–83, 1891.

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Eocene (Claiborne formation):	Feet.
1. Dark chocolate-tinted fine argillaceous massive sand, weathering to gray; contains numerous brown comminuted fragments of vegetable matter	8
	34

The gravel as it occurs under the loess beneath the crest of Crowleys Ridge, 1½ miles east of Wynne, is described in a section given on page 109 of this report.

Another instructive exposure on a small creek, 3 miles east of Wynne and one-eighth mile north of the St. Louis, Iron Mountain & Southern Railway, is described on page 70 of this report, and is illustrated by a graphic section showing the unconformable relation of the Lafayette formation to the underlying Claiborne formation, and the probably unconformable relation to the overlying Pleistocene deposits.

Gravels belonging to the formation are described in two sections given on pages 70 and 71, one located 2½ miles north of the site of old Wittsburg[1] and the other 4 miles east of Wynne. In each place the gravels rest upon the Claiborne formation.

St. Francis County.—A section which reveals the formation resting upon the Jackson formation and overlain by loess is exposed on Little Crow Creek about 3 miles east of Forrest City and about one-eighth of a mile south of the Chicago, Rock Island & Pacific Railway. This section is described on pages 76–78.

The formation is exposed at the base of a north-facing bluff of Little Crow Creek about 1 mile east of Forrest City and just south of the Chicago, Rock Island & Pacific Railway. The section is as follows:

Section on Little Crow Creek, 1 mile east of Forrest City.

Pleistocene (loess):	Feet.
3. Loess, faintly banded; becomes sandy and grades into next layer below	50
2. Light-gray fine compact sand with scattered pebbles	4
Unconformity (?); contact is irregular but not very sharp.	
Pliocene(?) (Lafayette formation):	
1. Gravel composed chiefly of subangular to partly rounded pebbles of flint and chert up to 4 or 5 inches in length, with a small percentage of smoothly rounded white, clear, and pink quartz pebbles up to 1 inch in length; the matrix consists chiefly of coarse gray, red, and yellow sand; fine light-gray sand resembling that of layer No. 2 is mixed with the gravels to a depth of a few inches to a foot below the top	6
	60

[1] Call, R. E., op. cit., pp. 69–71.

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Lee County.—Phillips post office (now discontinued) was located at the foot of the east-facing slope of Crowleys Ridge near the southern boundary of Lee County. In a gully just west of the site of the post office the following section is exposed:

Section in a gully just west of the site of Phillips post office.

	Feet.
Pleistocene:	
4. Loess, sandy at base; one fragment of a land shell observed	10
Unconformity, probably due to the creep of the loess down the slope from a higher level.	
Pliocene (?) (Lafayette formation):	
3. Red cross-bedded pebbly calcareous sand, drying with a hard, harsh surface; contains spherical concretions of sand and calcium carbonate up to 3 or 4 inches in diameter, which in places are segregated into botryoidal clusters	15
2. Light-gray cross-bedded sand containing a few small pebbles and scattered spherical concretions of sand and calcium carbonate	7
1. Gravel composed chiefly of iron-stained chert pebbles, reaching a maximum diameter of 3 or 4 inches	10
	42

Phillips County.—The following section is exposed in a ravine just north of the "Big Spring" on the east side of the ridge, 2½ miles north of Helena, Phillips County:

Section in ravine just north of "Big Spring" on the east side of Crowleys Ridge, 2½ miles north of Helena, Phillips County.

	Feet.
Pleistocene (loess):	
Poorly exposed, except 30 or 40 feet of massive gray loess in the basal portion	130
Unconformity somewhat obscured by weathering.	
Pliocene (?) (Lafayette formation):	
Coarse gray, reddish, and yellowish, irregularly bedded sand, with numerous scattered pebbles and small to large lenses and layers of gravel, interbedded with subordinate thin layers of laminated pink and drab clay; thick lenses of coarse cross-bedded sand were observed; in places the sands contain mechanically included balls of pink clay; gravel predominates in the basal 10 feet of the section, but is interbedded with lenses of coarse sand; the pebbles consist chiefly of subangular to partly rounded flint and chert up to 3 or 4 inches in diameter, with a few small, smoothly rounded quartz pebbles	80
	210

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The Lafayette materials of this section differ from those of most parts of the ridge north of Lee County in the predominance of sand and in the presence of thin beds of drab and pink-tinted, laminated clay. The gravels, however, appear to differ in no essential respect from the typical gravels observed at many localities in the ridge to the north.

The water of Big Spring emerges from the coarse gravel at the base of the Lafayette.

Near a small spring which emerges from the foot of the east slope of the ridge, one-quarter mile south of the Big Spring, are several gullies that reveal the contact between the Lafayette formation and the overlying loess. The section here is as follows:

Section in gullies near a small spring about 2¼ miles north of Helena and one-quarter of a mile south of the Big Spring, Phillips County.

	Feet.
Pleistocene (loess):	
Poorly exposed, except 25 feet of gray calcareous massive loess in the basal portion	80
Unconformity; the contact as seen in several exposures is absolutely sharp and undulates through a vertical distance of a foot or more in small exposures (Pl. IX, *B*).	
Pliocene (?) (Lafayette formation):	
Coarse gray cross-bedded sand, variegated with pink, red, yellow, and black, with interbedded thin layers of laminated drab to pink clay; in places the sand contains pebbles and water-rolled lumps of pink and drab clay	25
Concealed to the level of the Mississippi lowland	15
	120

Exposures in the northern outskirts of Helena at the foot of the east-facing slope of Crowleys Ridge reveal in places coarse, pebbly sands and gravels corresponding to the deposits referred to the Lafayette formation in the two preceding sections; at one place a layer of gravel 4 or 5 feet thick was observed immediately beneath the loess but the contact with the loess was not clearly exposed.

Western border of the Mississippi embayment.—Scattered remnants of gravel were observed on the hills of the Ozark province west of McAlmont, Pulaski County.

Two miles west of Beebe, White County, the Ozark hills rise 40 or 50 feet above the level of the Advance lowland. A few chert pebbles were observed scattered about on the Carboniferous sandstones and weathered shales which appear to compose the body of the hills.

Two miles south of Searcy the following section was examined in a cut of the Searcy branch of the Chicago, Rock Island & Pacific

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Railway on the east-facing scarp which separates the Ozark province from the Advance lowland:

Section in cut of Chicago, Rock Island & Pacific Railway 2 miles south of Searcy.

	Feet.
Pliocene (?) (Lafayette formation):	
Sandy loam	1–3
Gravel	½–1
Unconformity.	
Paleozoic (Carboniferous):	
Thin-bedded greenish-gray argillaceous sandstone	8
	12

The loam and gravel of this section blanket down over the slopes of the hill.

One and one-half miles south of Searcy, on the road leading to Higginson, a bed of gravel 5 or 6 feet thick was observed resting on Paleozoic rocks and overlain by 1 to 2 feet of sand and sandy loam.

A short distance northwest of the town of Judsonia, which is at the northwestern border of the Advance lowland, the Ozark hills rise 50 to 75 feet above the lowland level. In places on these hills a thin covering of gravel of the Lafayette formation was observed resting on sandstone of Carboniferous age. The gravels consist chiefly of chert, but several small, smoothly rounded pebbles of quartz were seen.

In Jackson County the Grandglaise terrace is partly separated from the Paleozoic rocks to the west by small valleys. At some places on the northwest slope of the ridge thus formed are numerous rounded pebbles, cobbles, and bowlders, probably derived from a bed of gravel of the Lafayette formation.

Five feet of reddish ferruginous sand, with pebbles in the basal portion, considered referable to the Lafayette formation, appears in a section one-half mile south of Grandglaise and just west of the St. Louis, Iron Mountain & Southern Railway. The sand rests on Eocene strata and is overlain by reddish loam of probable Pleistocene age. A description of this section is given on page 52 of this report.

About one-half mile north of Grandglaise very coarse gravel outcrops in the road; although poorly exposed, this bed probably rests upon Paleozoic rocks and is overlain by a loamy, claylike material, resembling a facies of the loess of Crowleys Ridge.

At Newark and vicinity, in Independence County, Upper Cretaceous deposits form the body of the Grandglaise terrace and are overlain by deposits of gravel of the Lafayette formation which

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range in thickness from a few inches to 25 feet or more. The gravels are overlain by a few inches to an observed thickness of 5 or 6 feet of yellowish, brownish, and reddish, more or less sandy and pebbly loam, which is believed to be of Pleistocene age.

The best exposure of the gravels observed in the vicinity of Newark is in a ballast pit of the St. Louis, Iron Mountain & Southern Railway on the edge of the Grandglaise terrace 2 miles west of the town. (See Pl. VIII, *B*, p. 88.)

Section exposed in a ballast pit of the St. Louis, Iron Mountain & Southern Railway 2 miles west of Newark, Independence County.

	Feet.
Pleistocene? (loess?):	
Yellow and brownish pebbly and sandy loam	3
Contact obscured by weathering.	
Pliocene (?) (Lafayette formation):	
Gravel composed of subangular to smoothly rounded pebbles of brown, gray, and reddish chert up to 3 inches in length, with a few small lenses of coarse reddish sand and sandy clay; some of the pebbles bear the prints of Paleozoic fossils; a talus covering partly obscures the basal 5 or 6 feet	20

The base of this section is about 10 feet above the level of the Advance lowland, along the border of which the railroad extends east and west. In a section exposed in a gully 1 mile north of Magness, Independence County, gravel of the Lafayette formation was observed resting on glauconitic sands of Upper Cretaceous age and overlain by a few feet of pebbly loam. (See section, p. 38.)

A bed of gravel capping a hill 2 miles north of Newark is described in a section given on page 38. Gravels cap the Grandglaise terrace at numerous places between Dota and Cord.

Remnants of gravel deposits, believed to represent the Lafayette formation, are scattered about the east-facing slopes of the hills of the Ozark province between Black Rock and Powhatan, in Lawrence County.

A few pebbles, probably representing remnants of the Lafayette formation, occur on the slopes of the Ozark hills just west of the ferry at Tabor, Clay County.

CORRELATION.

The deposits of gravel and sand in Mississippi, Tennessee, Kentucky, and southern Illinois to which the name Lafayette is applied, rest unconformably on Paleozoic, Cretaceous, and Tertiary strata and are overlain, in part, by loess of Pleistocene age. Exactly similar deposits of gravel and sand in Crowleys Ridge occupy an analogous position with reference to underlying Eocene strata of Wilcox, Clai-

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borne, and Jackson age and overlying deposits of loess of Pleistocene age. On lithologic and structural grounds the deposits in Crowleys Ridge may therefore be correlated with the gravels having the same relations east of Mississippi River.

The geologic series to which the Lafayette formation belongs has not been determined with certainty, chiefly because of the lack of paleontologic data. According to Chamberlin and Salisbury,[1] the formation is separated from the overlying loess by an unconformity which is indicated by a well-marked structural break and by the oxidation to which the pre-loessial materials have been subjected.

At some localities in Crowleys Ridge the Lafayette formation appears to be separated from the loess by a well-marked unconformity, but at many places the contact is more or less obscure; the materials composing the former have undoubtedly been subjected to strong oxidation.

The best and most convincing argument for the pre-Pleistocene age of the Lafayette formation is that based on the composition of the gravels. On this subject Salisbury[2] says:

> The gravels of Crowleys Ridge are, in all characteristics which are essential to the present discussion, like those of western Kentucky and Tennessee, like those of southern Illinois and southeastern Missouri. There are minor differences in their constitution, dependent on the differences of the rocks from which they are derived, but these are not especially significant, so far as the question of the age of the gravels is concerned. It is to be noted that the gravels of southern Illinois, of southeastern Missouri, of western Tennessee and Kentucky, as well as those of Crowleys Ridge, occupy a geographic position which makes it necessary to suppose that the drainage of the ice of the first episode passed through the region which they occupy. If these gravels date from this time they should contain pebbles of northern drift. It would not be necessary to suppose that all the gravel deposited by a stream springing from the glacier would necessarily be northern, since extra-glacial tributaries might bring in material from extra-glacial sources in the ordinary process of river degradation. But emphasize the importance of this latter consideration as we may, it yet remains an indisputable fact that were the conditions of drainage such that tributaries could bring gravel to their main in great quantities, the main itself, if springing from the ice, would inevitably bring something of glacial débris, which would be found mixed with the material of more local origin, which the tributaries might have brought in. And this would be true even if the accumulation of the gravels took place at an early stage of the glaciation of the first episode, long before the ice approached the latitudes under consideration; for the drainage basin of the Mississippi reaches several hundreds of miles to the northward and probably extended still farther in that direction at an early stage of the ice invasion, when the ice had so far spread itself over the British possessions as to prevent drainage into Hudson's Bay.

[1] On the relationship of the Pleistocene to the pre-Pleistocene formations of the Mississippi Basin south of the limit of glaciation: Am. Jour. Sci., 3d ser., vol. 41, pp. 359–377, 1891.

[2] On the relationship of the Pleistocene to the pre-Pleistocene formations of Crowleys Ridge and adjacent areas south of the limit of glaciation: Arkansas Geol. Survey Ann. Rept. for 1889, vol. 2, pp. 240–242, 244, 1891.

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If, then, the Orange sands and gravels were accumulated during the first glaciation of the first glacial epoch, as valley or estuary deposits, we should of necessity have northern material a constituent of these sands and gravels. Such, however, is not the fact. In the hundreds of exposures of gravel which the writer has seen, large numbers of which in various localities in Arkansas and in the other States already named have been examined in detail for this especial purpose, not a single pebble of demonstrably northern origin has ever been found. Northern pebbles have been found associated with pebbles derived from the gravels under consideration, but only in such situations that the secondary character of the deposits containing such pebbles was certain, or altogether probable, from considerations entirely independent of those here noted. And the freedom from northern gravel and sand does not characterize the Orange sands simply in their more southern distribution, where the local material might naturally be more abundant than to the north, but even up to the northern limit of the Orange sand regions scarcely more than a score of miles from the southern border of the glacial drift, the northern pebbles are likewise altogether absent. And it is not simply glacial pebbles that are wanting. The absence of glacial sand and silt from the Orange sand formation is equally conspicuous and significant.

* * * * * * *

And even if an occasional northern Archean pebble should hereafter be found in the Orange sand, we should not, on the strength of this evidence alone, regard our conclusion as invalidated, for the drainage basin of the Mississippi reaches well back into the area of Archean rocks, and it would not be at all surprising if Archean pebbles from this source should have found their way into the lower Mississippi Valley before the glacial period.

At nearly all the localities of the Lafayette formation examined in Crowleys Ridge the gravels, which are composed predominantly of flint and chert, contain scattered, smoothly rounded quartz pebbles, few more than 1½ inches in diameter. The small size of the pebbles and the evident long-continued wear to which they have been subjected suggest that they have been transported great distances. E. W. Shaw is actively engaged in a study of this subject and suggests the following as possible sources of the quartz: The veins of quartz cutting the crystalline rocks in the northern part of the Mississippi basin, probably not an adequate source; conglomerates in the Paleozoic rocks of the upper Mississippi basin; postulated gravel deposits of Cretaceous and Tertiary age in the same basin, now largely though probably not entirely, removed; and the crystalline rocks of the Piedmont area east of the Appalachian Mountains. The ultimate source of the quartz in the Paleozoic and later conglomerates of the upper Mississippi River basin would be either the crystalline rocks of Canada or those of the Piedmont; it seems improbable that any of the quartz has been derived from the Rocky Mountain region. The question of the possible transportation of quartz pebbles from the Piedmont region along the ancient drainage courses or shore lines has not been sufficiently studied.

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The evidence seems to be convincing that the materials composing the Lafayette formation in Crowleys Ridge were deposited before the continental glaciers of Pleistocene time had brought their load of materials down the Mississippi Valley from the far north to within a relatively short distance of the head of the Mississippi embayment; in other words, they were deposited in pre-Pleistocene time. How long the deposition of the gravels and sands of the Lafayette formation antedated the beginning of the Pleistocene is a matter of conjecture. Probably, however, the time was relatively short, geologically speaking. The thinness of the formation, its nearly horizontal attitude, and the unconsolidated condition of the materials would seem to preclude the lapse of any great length of time between its deposition and the deposition of the overlying loess, for the oscillations to which the Mississippi embayment was subjected prior to Pleistocene time and the accompanying erosion would probably have resulted in the complete destruction of the formation. The formation is believed, therefore, to be of late Pliocene age.

Quaternary system.

PLEISTOCENE SERIES.

LOESS.

AREAL DISTRIBUTION.

In Arkansas the materials classed as loess cap Crowleys Ridge or mantle its slopes from the Missouri State boundary on the northern border of Clay County southward to the southern extremity of the ridge, near Helena, Phillips County. Fragmentary erosion remnants of yellowish, reddish, and brownish argillaceous loam, which probably represent the loess, occur along the western margin of the Mississippi embayment, in places capping the Grandglaise terrace and elsewhere resting upon the east-facing slopes of the hills of the Ozark province.

North of Arkansas the loess forms the capping material of Crowleys Ridge to its northern extremity in Stoddard County, Mo., and is also present on Benton Ridge in Scott County, Mo.

East of the Mississippi lowland the loess occurs on the upland in a belt 5 to 25 miles or more in width, paralleling the Chickasaw Bluffs, and extending from southern Illinois southward through Kentucky, Tennessee, and Mississippi to Louisiana.

The general distribution of loess in North America has been summarized by Chamberlin and Salisbury[1] as follows:

> In North America the loess does not occur east of the Mississippi basin and has no great development east of the Wabash River. It is widespread in Illi-

[1] Chamberlin, T. C., and Salisbury, R. D., A college textbook of geology, pp. 887, 888, 1909.

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nois and the States along the Missouri and in the States along the Mississippi farther south. Within this area the distribution is peculiar in that it follows the main streams that led away from the Iowan drift sheet, and is found especially on the bluffs overlooking the valleys. On this account it was formerly known as the Bluff formation. In this bluff position it has more than its average thickness and coarseness of grain, and grows thinner and finer in grain back from the river bluffs until it is lost in a vanishing edge. At the same time its material loses its distinctive characteristics.

Just south of the borders of the Iowan and Wisconsin drift sheets it mantles many of the divides between the main streams, but farther south it is more confined to the valley borders. It has little regard for topography and can hardly be said to have an upper limit. Within the drift-covered part of the Mississipi basin it occurs (1) as a surface mantle overlying drift and (2) between sheets of drift. South of the drift there are in places distinct sheets of loess, sometimes separated by a well-developed soil zone. The surface of the lower sheet shows the effects of prolonged weathering and oxidation in some places. Loess occurs in isolated spots even as far west as Washington and Oregon.

STRATIGRAPHIC POSITION.

The loess forms the capping material of Crowleys Ridge, and where undisturbed from its original position rests on the Lafayette formation. The nature of the contact between the loess and the Lafayette formation in Crowleys Ridge is believed to be that of unconformity, for at several localities, notably in Cross, St. Francis, and Phillips counties, there is a structural break, more or less clearly marked, separating the two classes of deposits. (See Pl. IX, *B*, and fig. 1, p. 71.) However, at many places the contact is obscured by weathering and its true character is difficult to detect. In the eastern and northern parts of the Mississippi embayment other investigators have observed an unconformity between the two formations. The time hiatus represented by this unconformity is believed to include an undetermined portion of early Pleistocene time, and perhaps a relatively brief portion of late Pliocene time.

Throughout the extent of Crowleys Ridge deposits of loess are found mantling the slopes of the ridge, at many places entirely to the base; in places it is obvious that disturbances in the nature of landslides, creep, or redeposition have taken place, but at many places it is not so apparent that shifting of this character has occurred. However, more of the mantling is probably to be explained in this way than has been supposed by previous students of the ridge.

At numerous places north of Craighead County the loess has been entirely removed from the crest of the ridge by erosion, leaving the Lafayette formation as the capping material.

LITHOLOGIC CHARACTER.

The loess of Crowleys Ridge presents several facies of gray, brown, or reddish silt, varying in composition from typical loess, of very fine texture, to both argillaceous and sandy facies of loess.

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The evidence seems to [illegible]
the Lafayette formation [illegible]
the continental glaciers [illegible]
of materials down the [illegible]
within a relatively short [illegible]
embayment; in other w[illegible]
one time. How long the [illegible]
Lafayette formation ante[illegible]
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jected prior to Pleistocene [illegible]
probably have resulted in [illegible]
The formation is believed [illegible]

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In Arkansas the material [illegible]
mantle its slopes from the [illegible]
border of Clay County sou[illegible]
ridge, near Helena, Phill[illegible]
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Ozark province.

North of Arkansas the loe[illegible]
leys Ridge to its northern e[illegible]
is also present on Benton Rid[illegible]

East of the Mississippi low[illegible]
belt 5 to 25 miles or more in w[illegible]
and extending from southern [illegible]
Tennessee, and Mississippi to [illegible]

The general distribution of [illegible]
marized by Chamberlin [illegible]

In North America the l[illegible]
has no great development [illegible]

[1] Chamberlin, T. C., and [illegible]
1909.

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At numerous places y the loess has been entirely removed fro erosion, leaving the Lafayet ation

facies of gray, brown,

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The composition of loess has been described by Chamberlin and Salisbury[1] as follows:

> The term loess is used both as a textural and a formational name. Lithologically, it is a silt intermediate between sand and clay. It is generally free from stones of all sorts, except the concretions developed in it since its deposition. In the exceptional cases where stones occur in it, they are confined to its very bottom, or are found in loess which has slumped or been washed down from its original position. It is sometimes interstratified with sand, especially at its base, where it is thick. On slopes and at their bases loess is often mingled with slope wash, talus, etc.
>
> The loess contains angular, undecomposed particles of the commoner carbonates (calcite and dolomite) and silicates (feldspars, amphiboles, pyroxenes, micas, etc.), and several of the rarer silicates have been identified. Magnetite also is a common, though never an abundant, constituent. All these are subordinate to quartz. These constituents strongly suggest that the material of the loess was derived from the flour of the glacial mill. In color it is predominantly buffish brown, but in not a few places it has a grayish (bluish) cast a few feet below the surface.
>
> The loess often stands with vertical faces for long periods, where sand or clay would be degraded into slopes. Roads on the loess tend to assume the form of little canyons, because the silt of the roadbed is washed or blown away, while that on either side stands up with steep or even vertical slopes. Weathered faces of the loess often show a rude columnar structure, the columns being 1 to several feet in diameter. The loess, as a rule, shows no stratification, but in its coarser phases there is often some suggestion of such structure, and where interbedded with sand stratification is sometimes distinct.

In the more complete exposures of loess in Crowleys Ridge, as in the deep cut of the St. Louis, Iron Mountain & Southern Railway at Wynne (p. 109), a distinct banding of the materials, due to slight differences in color, texture, and composition, is discernible. In the Wynne section and at a few other places in the ridge a nearly horizontal dark band, resembling an old soil, has been observed traversing the body of the loess 10 to 20 feet below the surface. This may be the same as the old soil which has been traced by E. W. Shaw, of the United States Geological Survey, throughout a considerable part of the Gulf embayment. Apparently it means that the deposition of the loess was interrupted by an erosion interval, and this interval may have been between Iowan and Wisconsin time.

Although the loess of Crowleys Ridge is in the main massive, evidences of stratification have been observed at some places, particularly toward the base of the deposits; at many places the loess grades downward into basal sands or clays. Pebbles are not uncommon in the basal materials.

In bluff and gully exposures and in artificial cuttings the loess tends to stand in vertical walls. (See Pls. VII, *A*, IX, *A*, and X, *B*.)

Ten samples of loess and residual clay from selected localities in Crowleys Ridge and one sample of doubtful loess from the Grand-

[1] Op. cit., pp. 885–887, 888.

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A. LOESS EXPOSED IN A GULLY ON THE EASTWARD-FACING SLOPE OF CROWLEYS RIDGE NEAR HELENA, PHILLIPS COUNTY.

B. UNCONFORMABLE CONTACT BETWEEN THE LAFAYETTE FORMATION AND THE LOESS IN A GULLY NEAR A SMALL SPRING AT THE FOOT OF CROWLEYS RIDGE, A QUARTER OF A MILE SOUTH OF THE BIG SPRING AND 2¼ MILES NORTH OF HELENA.

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glaise terrace in Jackson County were submitted to E. W. Shaw, who has furnished the following report on their petrographic and mechanical characters:

The method used in studying the mineralogical composition of the specimens of loess consisted in examining first the material in its natural condition, the sample being taken from the interior of a specimen where there was no possibility of including extraneous dust; then a sample gotten by carefully washing a considerable amount of loess to get rid of the finest claylike particles; and, finally, particles obtained by treating this washed material with a heavy liquid, generally bromoform, to sort out the heaviest particles. The bromoform was usually diluted with benzene until it had a specific gravity of 2.75, sufficient to float the most abundant minerals, quartz, orthoclase, and microcline, and also the calcite which is present in some specimens, and allow the heavier particles, particularly the ferromagnesian minerals to settle to the bottom.

Specimen 26206: From 8 to 10 feet below surface in cut of St. Louis, Iron Mountain & Southern Railway 1½ miles east of Wynne, Ark. Full thickness of loess exposed at this place about 78 feet, apparently all in place. In general aspect this specimen is grayish-yellow with a slight brownish tinge, rather compact and claylike, and yet including numerous small, irregular tubes, probably root impressions running through it in various directions. Compared with average loess this specimen seems to be rather unusually fine grained and homogenous. Only a very small proportion of the grains are so fine that it is impossible or even difficult to determine their mineralogical identity. On the other hand, grains large enough to be ordinarily termed sand grains are rare. Besides quartz and orthoclase (which is more or less altered) other feldspars are present, and also biotite, hornblende, zircon, fluorite, rutile, tourmaline, and apatite. Epidote, muscovite, and sillimanite are present in particles barely large enough to identify.

Specimen 26207: From 12 or 15 feet below surface in cut of St. Louis, Iron Mountain & Southern Railway 1½ miles east of Wynne, Ark. This specimen is compact and has a decided carbonaceous appearance, its color being a rather dark brownish gray. It is much like No. 26206 except that it is not quite so uniform in grain and it seems to lack biotite, fluorite, and albite.

Specimen 26208: From 15 or 20 feet below surface in cut of St. Louis, Iron Mountain & Southern Railway 1½ miles east of Wynne, Ark. This specimen has a dirty yellowish color, is rather hard and coherent, and is made up of quartz, chert, muscovite, several feldspars, zircon, sillimanite, staurolite, and possibly other minerals.

Specimen 26209: From 30 or 40 feet below surface in cut of St. Louis, Iron Mountain & Southern Railway 1½ miles east of Wynne, Ark. This specimen is a light brownish yellow in color and is of a texture which might be stated as that of typical loess. Quartz constitutes about 90 per cent of this specimen; chert is abundant, and other minerals, particularly the feldspars, but also muscovite, biotite, epidote, zircon, and hornblende, are present in scattered particles.

Specimen 26210: From 51 to 56 feet below surface in cut of St. Louis, Iron Mountain & Southern Railway 1½ miles east of Wynne, Ark. This specimen is of a reddish-brown color and unusually clayey; probably an old residual soil. It differs from most of the other samples in that a much larger portion is impossible of mineralogical determination, chert particles are unusually numerous, the feldspars are much weathered, and it seems to contain little, if any apatite, hornblende, or orthoclase.

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Specimen 26211: From about 60 feet below the surface in cut of St. Louis, Iron Mountain & Southern Railway 1½ miles east of Wynne, Ark. This specimen is of a light buff color, with a decided pinkish tinge and mottled with yellow. The minerals are quartz, chert, several feldspars, biotite, muscovite, tourmaline, zircon, rutile, kyanite, and garnet.

Specimen 26212: From 30 or 35 feet below the surface at the west end of Elm Street, Helena, Ark. This specimen is of a dark gray, differing markedly in containing much calcite, as well as the more abundant minerals, quartz, and some flint, orthoclase, microcline, epidote, biotite, and zircon.

Specimen 26213. From about 80 feet below the surface at the west end of Elm Street, Helena, Ark. This specimen is of a dark gray, differing markedly in color from most loess, and resembling the old loess underlying the Illinoisan till in southern Illinois. It has a typical loess texture, being quite porous and absorbent. It is made up principally of quartz and chert, but contains much more or less altered orthoclase, microcline, and probably other feldspars, muscovite, sillimanite, hornblende, epidote, and zircon.

Specimen 26214: From 8 or 10 feet below surface one-half mile southwest of Grandglaise, Ark. This specimen is reddish-buff in color and is not a very typical sample of loess, being much less pervious and more like residual clay. The minerals observed are quartz and flint, in particles having a considerable range in size, muscovite, biotite, magnetite, zircon, tourmaline, epidote, sillimanite, and apatite.

Specimen 26215: From near bottom of gully 15 feet deep 3½ miles west of Paragould, Ark. This specimen is of a brownish-buff color and not very porous. Probably the loess here has crept a little. It contains in addition to quartz many rather large grains of biotite, chert, and hornblende, and smaller particles of magnetite, zircon, rutile, brookite, garnet, and sillimanite.

Specimen 26216: From 20 to 23 feet below surface in cut of Chicago, Rock Island & Pacific Railway one-quarter mile east of Forrest City, Ark. This specimen is of a dark grayish-brown color, and carbonaceous in appearance, but fine grained and homogeneous. The minerals observed are quartz, flint, muscovite, feldspar of several varieties, augite, magnetite, rutile, tourmaline, and kyanite.

A part of each specimen was sent to the United States Bureau of Soils, which very generously made the mechanical analyses given in the following table, according to its standardized method:

Mechanical analyses of 10 samples of loess and loesslike material from Crowleys Ridge, Ark., and of one sample from the Grandglaise terrace.

	26206	26207	26208	26209	26210	26211	26212	26213	a26214	26215	26216
Fine gravel (2 to 1 mm.)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Coarse sand (1 to 0.5 mm.)	.0	.2	.4	.0	.0	.0	.0	.0	.2	.2	.2
Medium sand (0.5 to 0.25 mm.)	.1	.1	.3	.0	.6	.1	.1	.1	.1	.1	.1
Fine sand (0.25 to 0.1 mm.)	.2	.3	.6	.1	.6	1.1	.2	.1	6.0	.5	.2
Very fine sand (0.1 to 0.05 mm.)	3.8	2.6	7.0	9.5	7.7	9.4	7.8	5.6	10.6	4.4	4.8
Silt (0.05 to 0.005 mm.)	84.2	82.3	78.2	83.2	59.3	82.3	86.9	85.5	70.3	78.2	84.7
Clay (0.005 to 0 mm.)	11.4	14.3	12.9	7.0	31.8	6.9	4.7	8.6	12.5	16.4	10.0

a Sample from one-half mile southwest of Grandglaise, Jackson County, Ark.

The following analyses of samples of loess from Wisconsin, made for W. C. Alden by the Bureau of Soils in 1910, are inserted for purposes of comparison:

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Mechanical analyses of samples of loess from Wisconsin.

	23189	23190	23191
Fine gravel (2 to 1 mm.)	0.0	0.0	0.1
Coarse sand (1 to 0.5 mm.)	.0	.0	.1
Medium sand (0.5 to 0.25 mm.)	.0	.2	.1
Fine sand (0.25 to 0.1 mm.)	.7	1.0	1.7
Very fine sand (0.1 to 0.05 mm.)	19.6	5.1	18.2
Silt (0.05 to 0.005 mm.)	64.8	81.5	63.1
Clay (0.005 to 0 mm.)	14.7	12.2	16.4

23189. Loess, Bridgeport, Crawford County, Wis., near Mississippi River.
23190. Loess on late Wisconsin drift, Columbia County, Wis.
23191. Composite of loess loams; Driftless Area near Baraboo, Wis.

THICKNESS.

On Crowleys Ridge the loess varies from a thin veneer to a layer with a measured thickness of 139 feet. In general, the deposits are thinner north of Craighead County than south of that county; the maximum thickness of 139 feet is shown by the record of a well boring on the ridge near Helena, Phillips County (see log, p. 238), and a thickness of 130 feet was measured by the aneroid in the section at the Big Spring, 2½ miles north of Helena (see p. 94).

PHYSIOGRAPHIC EXPRESSION.

Although the existence of Crowleys Ridge is due to the resistance to erosion offered by the Eocene strata which compose the core of the ridge, the detailed surface features are determined chiefly by the loess which almost completely covers its crest and slopes. Where erosion has advanced to a mature stage the topography produced by the loess is characterized by smoothly rounded slopes and broad, shallow valleys; where the conditions have favored the rapid cutting of small valleys and deep ravines the loess stands up about their sides in nearly vertical walls. These extremes and intermediate stages are represented in the topography of the ridge.

PALEONTOLOGIC CHARACTER.

The only fossils found in the loess of Arkansas are the shells of various species of land mollusks and one bivalve fresh-water mollusk; these have been observed only in the southern part of Crowleys Ridge in Phillips, Lee, and St. Francis counties, where at certain places numerous well-preserved specimens are scattered through the materials. Call[1] has published lists of species from several localities. Lists of species from three localities identified by Paul Bartsch and a list from one of these localities identified by William H. Dall are given on pages 107 and 108 of this report.

[1] Call, R. E., The geology of Crowleys Ridge: Arkansas Geol. Survey Ann. Rept. for 1889, vol. 2, pp. 39, 49, 166–168, 1891.

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LOCAL DETAILS.

The loess is exposed at hundreds of places in Crowleys Ridge. Along the western margin of the Mississippi embayment there are scattered remnantal deposits of reddish and yellowish loamy clays which rest upon either the Paleozoic rocks of the east-facing slopes of the hills of the Ozark province or form the capping materials of the Grandglaise terrace.

A few of the more complete exposures of loess in Arkansas will be described in following paragraphs.

Helena, Phillips County.—At the southern extremity of Crowleys Ridge, west of Helena, the loess attains its greatest thickness in Arkansas—139.7 feet—determined by a boring on the ridge west of the town. (See log, p. 238.) Good exposures occur in road cuttings, other artificial excavations, and ravines. The materials are gray to yellowish and brownish in color and contain numerous small irregular concretions of calcium carbonate, apparently distributed indiscriminately through the mass. For the most part the materials appear to be massive, but at one or two fresh cuttings faint banding has been observed. The well-preserved remains of land mollusks are numerous in places. The following is a section prominently exposed in an excavation near the west end of Elm Street, Helena:

Section in an excavation near the west end of Elm Street, Helena.

Pleistocene (loess):	Feet.
Gray massive calcareous loess exhibiting faint banding; contains scattered remains of land shells throughout nearly the whole thickness, and at scattered intervals the shells are bunched together in large numbers. (See statement of petrographic character, sample No. 26212, and mechanical analysis of same sample in the table, p. 104)	75
Very dark greenish gray (wet) compact, massive, tough, finely arenaceous loess, with an oxidized zone a few inches to 1 foot thick in the upper portion; resembles the loess in texture, but differs in color and plasticity from common loess. (See statement of petrographic character, sample No. 26213, and mechanical analysis of same sample in the table, p. 104)	10
	85

The following fossils collected from the upper 75 feet of loess at this locality and from materials corresponding to this layer at near-by localities (field No. 269) were identified by Dr. Paul Bartsch:

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Fossils from loess at Helena, Ark.

Polygyra appressa Say.
Polygyra zoleta Binney.
Polygyra monodon Rackett.
Polygyra elevata Say.
Polygyra albolabris Say
Polygyra multilineata Say.
Polygyra stenotrema Ferussac.
Pyramidula alternata Say.
Pyramidula perspectiva Say.
Helicodiscus parallelus Say.
Conulus fulvus Draparnaud.
Zonitoides arboreus Say.
Zonitoides minusculus Binney.
Gastrodonta ligera Say.
Gastrodonta sp.
Vitrea sp.?
Vitrea indentata Say.
Succinea luteola Gould.
Circinaria concava Say.

A thickness of 130 feet of loess was measured by the aneroid in a section exposed in a gully near the Big Spring, 2½ miles north of Helena, a description of which is given on page 94 of this report. Another section one-quarter mile south of the Big Spring, which shows the unconformable relations of the loess to the underlying Lafayette formation, is described on page 95. (See Pl. IX, *B*, p. 102.)

Forrest City, St. Francis County.—On the north-facing side of a deep cut of the Chicago, Rock Island & Pacific Railway one-quarter mile east of Forrest City, St. Francis County, the following section is exposed:

Section in cut of Chicago, Rock Island & Pacific Railway one-quarter mile east of Forrest City.

Pleistocene (loess):	Feet.
Gray massive calcareous loess with concretions of calcium carbonate; grades downward into next layer below	20
Dark-brown loess resembling an old soil, with concretions of calcium carbonate; grades downward into next layer below. (See statement of petrographic character, sample No. 26216, and mechanical analysis of same sample in the table on p. 104)	3
Yellowish loess with concretions of calcium carbonate; grades downward into next layer below	8
Gray massive loess with concretions of calcium carbonate	11
Gray massive loess with faint horizontal lines of yellow iron oxide simulating bedding planes; contains calcium carbonate concretions and becomes sandy and ferruginous in the basal 4 or 5 feet; contains numerous land shells and one fresh-water species (see list below)	14
	56

When examined in 1905, 4 feet of pebbly cross-bedded sand streaked with yellow, probably belonging to the Lafayette formation, was observed beneath the loess in the center of the cut. In 1912 this had become concealed by talus.

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The following fossils collected from the lowermost layer of the section just described were identified by Dr. Paul Bartsch:

Fossils from loess in cut of Chicago, Rock Island & Pacific Railway one-quarter mile east of Forrest City (Field No. 267).

Polygyra stenotrema Ferussac?
Polygyra appressa Say.
Polygyra monodon Rackett.
Polygyra sp.?
Polygyra sp.?
Circinaria concava Say.
Circinaria concava Say (young).
Sphærium sp.? (fresh-water bivalve).
Helicodiscus parallelus Say.
Strobilops labyrinthica texasiana Pilsbry.
Helicina orbiculata Say.
Pomatiopsis lapidaria Say.
Succinea avara Say.
Lymnæa parva Lea.
Vitrea indentata umbilicata Singley.
Zonitoides minusculus Binney.
Bifidaria contracta Say.
Bifidaria corticaria Say.
Bifidaria sp.?

In a collection made from the same locality in 1905 (U. S. Nat. Mus. catalogue No. 6405) William H. Dall has identified the following species:

Planorbis trivolvis Say.
Pomatiopsis lapidaria Say.
Polygyra hirsuta Say.
Polygyra monodon Rackett.
Succinea avara Say.
Circinaria concava Say.
Heliocodiscus lineatus Say.
Zonitoides arboreus Say.
Bifidaria contracta Say.
Strobilops labyrinthicus Say.
Helicina occulta Say.

Seventy feet of loess is exposed in the section on Little Crow Creek described on page 76. (See Pl. VII, *A*.) From a layer 50 to 65 feet below the surface in this section Dr. Bartsch identified the forms Polygyra sp.? and Sphærium sp.? (a fresh-water bivalve).

Sixty feet of loess appears in a bluff on St. Francis River, where the river strikes against the foot of the eastern slope of the ridge 8 or 9 miles northeast of Forrest City. (See section, p. 76.)

Wynne, Cross County.—The cut of the St. Louis, Iron Mountain & Southern Railway through the crest of Crowleys Ridge 1½ miles east of Wynne, Cross County, reveals the full thickness of the loess at that place. The cut is over 80 feet deep and has been widened several hundred feet by the removal of material used for ballast on the railroad embankments. In the north-facing side of the excavation, including a deeper trench extending in a linear direction through the cutting, the following section is exposed:

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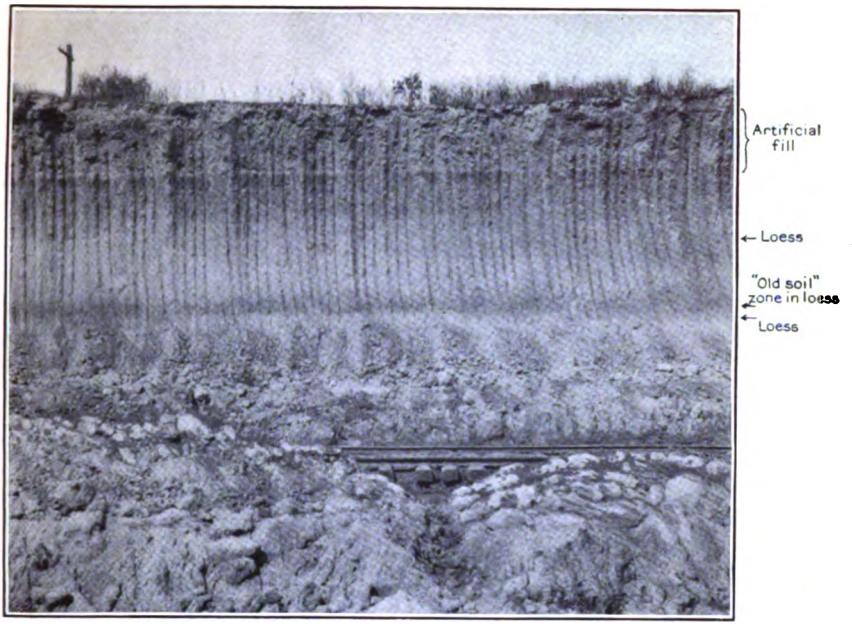
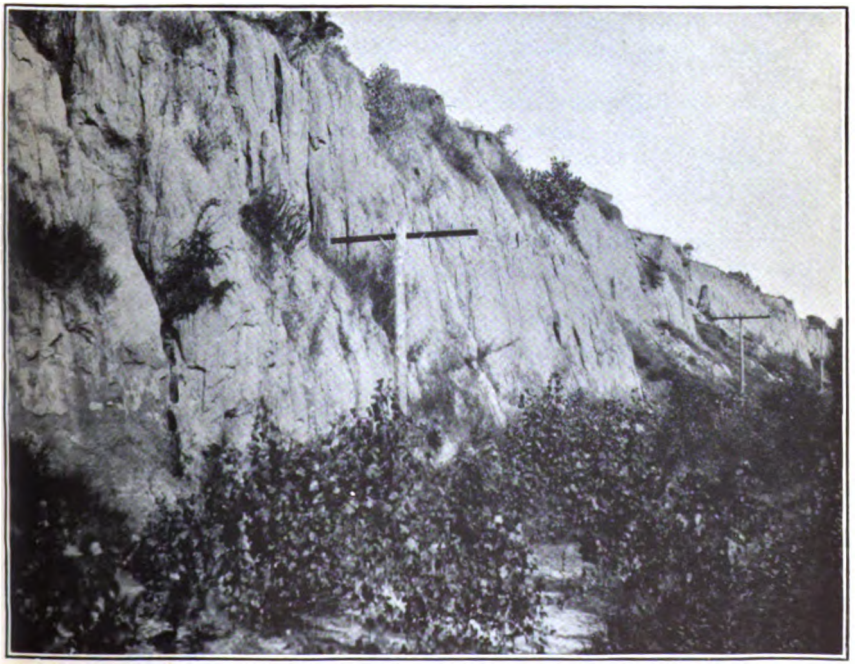


A. "OLD SOIL" ZONE IN LOESS ON SOUTHWARD-FACING SIDE OF CUT OF ST. LOUIS, IRON MOUNTAIN & SOUTHERN RAILWAY 1½ MILES EAST OF WYNNE, CROSS COUNTY.



B. LOESS EXPOSED IN A CUT OF THE CHICAGO, ROCK ISLAND & PACIFIC RAILWAY THROUGH CROWLEYS RIDGE A QUARTER OF A MILE EAST OF FORREST CITY, ST. FRANCIS COUNTY.

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Section in cut of St. Louis, Iron Mountain & Southern Railway 1½ miles east of Wynne.

	Feet.
Pleistocene (loess):[1]	
7. Light-gray facies of loess	15
6. Dark-brown facies of loess, resembling an old soil; contains a few small brown chert pebbles	6
5. Light-gray facies of loess	30
4. Harsh red ferruginous facies of loess mottled in places with gray	5
3. Light-gray facies of loess tinted with pink	12
2. Light pinkish-gray, finely arenaceous clay grading downward into light greenish-gray argillaceous sand, containing numerous small concretions of impure limonite and a few small pebbles of chert and quartz; resembles loess in texture	8–10
Unconformity; contact is sharp and varies in vertical position as much as 2 feet in a horizontal distance of 2 yards.	
Pliocene (?) (Lafayette formation):	
1. Gravel composed chiefly of brown and gray subangular to partly rounded pebbles of flint and chert up to 6 inches in length, with a small percentage of smoothly rounded to partly rounded white or clear quartz pebbles up to 1 inch in length	3

The different facies of loess described in this section produce distinct bands in the deposits; the layers are not sharply defined but grade into each other. At one place on the south-facing side of the same cut the so-called old soil zone, corresponding to layer No. 6 of the section, is well exposed in a less complete section, as follows:

Section on south-facing side of a cut of the St. Louis, Iron Mountain & Southern Railway 1½ miles east of Wynne.

	Feet.
Recent:	
4. Artificial fill of loess	6
Pleistocene (loess):[2]	
3. Light-gray facies of loess; grades downward into next layer below	12
2. Dark-brown facies of loess, resembling an old soil zone; grades downward into next layer below	3
1. Light-gray facies of loess, similar to layer No. 3	5
	26

The dark band, layer No. 2, of the section is well shown in the photograph reproduced in Plate X, *A*.

Forty or 45 feet of loess is well exposed in a south-facing slope on a small creek 3 miles east of Wynne and one-eighth mile north

[1] See statements of petrographic character and mechanical analyses as follows: Layer No. 3, sample No. 26211, text and table, p. 104; layer No. 4, sample No. 26210, p. 103, and table, p. 104; layer No. 5, sample No. 26209, p. 103, and table, p. 104.

[2] See statements of petrographic character and mechanical analyses as follows: Layer No. 1, sample 26208, p. 103, and table, p. 104; layer No. 2, sample 26207, p. 103, and table, p. 104; layer No. 3, sample 26206, p. 103, and table, p. 104.

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of the St. Louis, Iron Mountain & Southern Railway; this section is described in detail on page 71 of this report.

Eighteen feet of loess appears in the upper part of the section exposed in a gully about 4 miles east of Wynne and one-quarter mile south of the St. Louis, Iron Mountain & Southern Railway, described on page 70.

In the section 2½ miles north of the site of Old Wittsburg, described on page 70, the thickness of the loess is 49 feet; concretions of calcium carbonate are abundant in the middle portion of this exposure.

Jonesboro, Craighead County.—In the vicinity of Jonesboro, Craighead County, are numerous exposures of loess, which commonly appear in the form of a dark loam, lacking calcareous concretions and fossils; light-colored and reddish facies of the loess are also to be seen. In places the argillaceous content increases and the materials become dark loamy clays. The thickness is as a rule 30 feet or less. One of the best exposures has been described by Call[1] as follows:

Three or four miles west of Jonesboro, on the line of the Kansas City, Fort Scott & Memphis Railway, are several cuts across low spurs of the ridge. These cuts disclose only the loess clays, but show them better than any other section in the county. They may be here divided into three layers on the usual color basis, as follows:

	Feet.
1. Siliceous or sandy humus, with much clay	2
2. Tough red clayey loess, much fissured, the faces of the fissures black with dendritic segregations of manganese. This member is removed for railway ballast and is so hard as to require blasting	7
3. Looser, yet tough, more yellow soil, weathering into vertical faces	15

This cutting is duplicated at several places. This one shows the characteristic mode of occurrence and coloration of the loess.

Greene County.—The loess in Crowleys Ridge in Greene County commonly appears either as reddish, argillaceous loam or as lighter-colored facies of loam. Along the public road leading west from Paragould loess, for the most part poorly exposed, is the only material to be seen in the road ditches and cuttings. In a gully at the roadside, 3½ miles from town, a thickness of 15 feet of the loess was observed; a statement of the petrographic character of a sample of this material (sample 26215) and a mechanical analysis of the same sample are given on page 104. From 4 miles west of town westward across the ridge to the margin of the Advance lowland, a thin blanket of loess not exceeding 5 or 6 feet forms the surface material and rests upon gravels of the Lafayette formation, which appear at frequent intervals.

[1] Call, R. E., op. cit., p. 89.

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At Gainesville red, mottled, and light-colored facies of the loess are exposed in the road ditches, and in places the materials contain numerous small, irregular concretions of calcium carbonate. In places in Greene County the loess has been entirely eroded away from the crest of the ridge, leaving the underlying gravels of the Lafayette formation as the capping materials.

In the Advance lowland, in the northwestern part of Greene County, is an isolated ridge known as Jones Ridge, which is composed mainly of materials believed to represent the loess. The ridge trends in a northeast-southwest direction between Cache River and the St. Louis, Iron Mountain & Southern Railway, is 3 or 4 miles long, one-quarter to one-half mile wide, and 30 or 40 feet high. The surface, though considerably dissected, presents smoothly rounded gentle slopes, offering no complete exposures of the materials. A few poor exposures on the slopes of the ridge reveal a dark, somewhat sandy clay loam, grading downward into reddish argillaceous sand. As these materials resemble closely facies of loess observed in Crowleys Ridge to the east in Greene County, they have been correlated with that formation.

Clay County.—In Clay County the loess of Crowleys Ridge appears in the form of light-yellow, brown, and dark-red, noncalcareous, more or less sandy and argillaceous loams, in places grading downward into sands or clays. At no place where observations were made did the loess exceed 30 feet in thickness. At numerous places the loess has been entirely eroded away from the crest of the ridge, leaving the gravels of the Lafayette formation as the capping materials.

Western margin of the Mississippi embayment in Arkansas.—Loesslike clays have been observed resting on Paleozoic limestone just west of the ferry over Current River at Tabor, Clay County. They form hills just west of the ferry over Black River at Powhatan, Lawrence County, where they probably rest on Paleozoic rocks. Yellow loams, probably representing the loess, cap the Grandglaise terrace between Strawberry, Lawrence County, and Newark, Independence County, but at many places the loess has been largely eroded away and is now represented only by a thin veneer of sandy loam.

South of Grandglaise in Jackson County, the Grandglaise terrace is capped in places by 10 or 12 feet of reddish, massive, finely arenaceous, argillaceous loam resembling loess; this material strongly suggests certain facies of the loess of Crowleys Ridge. The best exposure of the loam examined in the Grandglaise terrace was in a south-facing bluff one-half mile south of Grandglaise, and just west of the St. Louis, Iron Mountain & Southern Railway; a description of this section is given on page 52 of this report. A statement

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of the petrographic character of a sample of loess taken from layer No. 5 of this section (sample 26214) and a mechanical analysis of the same sample are given on page 104.

CORRELATION.

The Pleistocene age of the American loess has long been a recognized fact among students of American geology. Chamberlain and Salisbury[1] discuss the age of the loess as follows:

> The relations of the loess to the several drift sheets make it clear that it was accumulated at different stages of the glacial period, but within the glaciated area the accumulation at one of these stages exceeds that at all others both in volume and areal extent. The loess deposited at this stage is often referred to as "the loess," and is usually correlated in time with the Iowan drift. It is at least later than the Illinois sheet of drift, which it mantles, and earlier than the Wisconsin drift, which overlies it. Locally a thin mantle of loess overlies the Wisconsin drift, even its later parts. No considerable body of loess older than the Illinois drift is known.

In his earlier studies of the loess Salisbury,[2] in terms of the classification then in use, referred the loess of Crowleys Ridge to the first glacial epoch. On the evidence of the soil zone to which reference has previously been made, he subdivided the loess into two parts, the older and lower of which he correlated with the first episode of the first glacial epoch, and the upper and younger of which he referred to the second episode of the first glacial epoch. He regarded the part of the loess above the soil zone as corresponding to the main body of the loess. In terms of the present classification of the glacial drift the main body of loess is correlated in time with either the Iowan drift or with the Peorian interglacial stage,[3] which immediately succeeded the Iowan invasion. In this connection it should be stated that in the southern part of Crowleys Ridge, where the so-called soil zone is most distinctly developed, the thickest body of loess is below and not above the soil zone. The soil zone, at most of the exposures examined, is only 10 or 20 feet below the top of the ridge, while in places the thickness of the loess below the zone is 55 or 60 feet; at one locality a thickness of 40 feet of loess was observed above the soil zone.

If the loess above the soil zone corresponds to the main body of the loess in other parts of the Mississippi basin, that below the soil zone is of course older, though the interval between the deposition of the two parts would not necessarily be of relatively long duration.

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[1] A college textbook of geology, p. 888, 1909.

[2] Salisbury, R. D., On the relationship of the Pleistocene to the pre-Pleistocene formations of Crowleys Ridge and adjacent areas south of the limit of glaciation: Arkansas Geol. Survey Ann. Rept., 1889, vol. 2, pp. 232–234, 1891.

[3] Calvin, Samuel, The Iowan drift: Jour. Geology, vol. 19, pp. 599–602, 1911.

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The question of the significance to be attached to the so-called soil zone is one to which sufficient attention has probably not been given. On the hypothesis that the upland loess was deposited chiefly through the agency of wind it does not seem improbable that such a zone might be formed within the main body of the loess, due to a temporary change in the prevailing direction of the wind, or to a temporary advantage gained by vegetation in the adjacent area of mud flats from which the materials were supplied to the wind. If this be true, the formation of a soil zone would not necessarily have direct connection with changes taking place in the main area of glaciation farther north.

According to Dr. Paul Bartsch, who determined the species listed on page 108, the contained fossils throw no light on the exact correlation of the loess. Shimek,[1] discussing the same subject, says:

> The fossil mollusks do not enable us to determine the age of any of the Pleistocene formations. The fossils of the Aftonian are not sufficiently distinct from those of modern alluvium to permit the drawing any conclusion other than that the conditions of deposition were much the same. They do not enable us to distinguish between the loesses, for the fossils of the gray and the yellow loesses are, in larger series, essentially the same. * * *
>
> In no known Pleistocene deposit is there a vertical gradation of species which can be accounted for on climatic grounds. * * *
>
> Southward along the Mississippi the loess molluscan fauna changes in essentially the same manner as the modern fauna of the surface. At Hickman, Ky., the larger helices (so prominent in the southeastern modern fauna) already appear in large numbers and *Pyramidula solitaria*, carinate *Pyramidula alternata*, *Polygyra tridentata*, very large *P. albolabris*, large *P. profunda*, a few *P. elevata*, *P. fraterna*, *P. fraudulenta*, *P. appressa*, *Omphalina fuliginosa*, large *Circinaria concava*, more abundant *Pyramidula perspectiva*, and *Gastrodonta ligera*. These species already form the most conspicuous feature of the loess fauna. *Helicina occulta* still appears, though here approaching its southern limit. Still farther south at Dyersburg, Tenn., a similar fauna appears in the loess, but *Helicina occulta* is not common, reaching here its southern limit, and *Pyramidula striatella*, so common in the north, also becomes rare. Still farther south on the west side of Mississippi River at Helena, Ark., the loess fauna becomes still more characteristically southern, and in addition to the larger helices already mentioned the large form of *Succinia ovalis*, *Omphalina kopnodes*, *Vitrea placentula*, and *Helicina orbiculata* appear in conspicuous numbers. The last three species are distinctively southern. *Helicina occulta* has wholly disappeared and its place has been taken by *Helicina orbiculata*. The richly fossiliferous loess of Natchez and Vicksburg, Miss., also contains the forms common at Hickman and Helena, and the presence of *Polygyra obstricta*, *P. inflecta*, and *P. stenotrema* still further stamps the fauna as distinctively southern.

[1] Shimek, Bohumil, The significance of Pleistocene mollusks: Science, new ser., vol. 37, pp. 506, 507, 508, 1913.

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ALLUVIUM.

GENERAL FEATURES.

Areal distribution and thickness.—The Advance lowland between Crowleys Ridge on the east, the Ozark province on the northwest, and the Coastal Plain uplands southwest of Arkansas River is underlain by 100 to 200 feet of alluvial deposits, chiefly referable to the Pleistocene epoch. A subordinate portion of the deposits are of Recent age. The Pleistocene alluvium comes to the surface in the interstream areas, or more exactly in the inter-floodplain areas of the lowland.

The Mississippi lowland throughout its extent in Arkansas and the adjoining States of Missouri, Kentucky, Tennessee, and Mississippi is also underlain to depths of 100 to 225 feet by alluvium which belongs to both the Pleistocene and Recent epochs. In this area the deposits of the two epochs have not been so accurately differentiated as have the alluvial deposits of the Advance lowland.

A belt of undulating land a few feet higher than the Mississippi lowland and nowhere more than 5 or 6 miles wide, which borders Crowleys Ridge on the east from Clay County southwestward to the southern part of Craighead County, is believed to be a remnant of a Pleistocene plain or terrace corresponding in age to the interstream plains of the Advance lowland.

Sikeston Ridge or Big Prairie, a narrow ridge about 20 feet high, which extends from south of Lake St. John, Scott County, Mo., to New Madrid, New Madrid County, Mo., is believed to be composed of Pleistocene deposits. A similar low ridge extends with several interruptions from the southern part of Stoddard County, Mo., a little west of south in a slightly sinuous course through Dunklin County, Mo., into the northern part of Mississippi County, Ark.; from north to south the different parts of this ridge are known respectively as Rosebriar Prairie, West Prairie, Grand Prairie, and Big Lake Highlands. This ridge is also believed to be composed of Pleistocene deposits.

The Pleistocene alluvium rests on undifferentiated deposits, chiefly of Eocene age but in part of Cretaceous age.

In the Advance lowland the Pleistocene alluvium comes to the surface in the inter-floodplain areas, but in the broad floodplains of the streams it is overlain by Recent alluvium, the thickness of which has not been determined at any point but which probably nowhere exceeds 75 feet.

Although in the Mississippi lowland the Pleistocene and Recent alluvial deposits have not been satisfactorily differentiated, it is

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believed that the former are concealed by the latter, except in the few slightly elevated areas previously described, concerning which there is reason, more or less well founded, for believing that the Pleistocene comes to the surface.

Lithologic character.—The Pleistocene alluvium is composed of loams, clays, sands, and gravels, which though irregularly bedded in detail, have in general assumed definite stratigraphic positions. Where the complete sequence of the deposits exists, as in the interstream areas of the Advance lowland, there is a downward gradation from fine surface silts or loams through compact clays and fine sands to coarse sands and gravels at the base. This arrangement of the materials has been determined in scores of well borings. Except near the surface the deposits appear to be rather strongly calcareous, as shown by the almost universally hard waters which they yield. The deposits appear also to be rather strongly ferruginous, although the iron is distributed more irregularly than the lime. In the surface materials the iron appears in places in the form of small limonite concretions, and where these are numerous give rise to the so-called "buckshot" soils of the area.

The silty subsoil clays are compact and almost impervious to water and are locally termed "hardpan." They range in thickness from a few feet to a maximum measured thickness of 75 feet, and vary in color from a light ashen gray through yellow and brown to dark red. The subsoil clays and the underlying fine sands are exposed at a few places in river bluffs, gullies, and artificial cuttings. The stream incisions are nowhere deep enough to reveal the coarse sands and gravels which compose the basal portion of the deposits, and the character of these materials has been determined by well borings.

Dark carbonaceous clays, logs and limbs of trees, and peaty accumulations representing buried swamp deposits, are occasionally encountered in well borings. Shells have been reported from a few well borings. With these exceptions, the materials have yielded no fossil remains.

In the northern part of the Advance lowland in Arkansas and along the northwestern border of the lowland are areas characterized by successive low ridges of sand and sandy loam, apparently bearing some close relation to the alluvial lands bordering the rivers. However, many of the ridges rise above the extreme high water level of the present streams and in places the materials appear to rest on the light gray silty clays which constitute the subsoil throughout the greater part of the interflood plain areas of the Advance lowland, and may therefore have been deposited in late Pleistocene time, sub-

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sequent to the formation of the clays and prior to the deposition of the Recent flood-plain materials.

Physiographic expression.—The gently undulating prairies and timbered lands of the interstream areas of the Advance lowland are the surface expression of the Pleistocene alluvial deposits. The prairies represent the least altered portions of the original Pleistocene plain; the timbered lands represent various stages in the process of erosion, which on account of the low gradient of the streams, is with extreme slowness reducing the plain to base-level.

LOCAL DETAILS.

As previously stated, the complete sequence of the Pleistocene alluvial deposits is not revealed by natural exposures. The upper portion of the alluvium appears at scattered localities in stream bluffs, gullies, road, and railroad cuttings. A few such sections are described on following pages.

Cloverbend, Lawrence County.—A bluff on Black River at Cloverbend, Lawrence County, reveals the following section:

Section on Black River at Cloverbend, Lawrence County.

Pleistocene alluvium:	Feet.
White "buckshot" clay, very hard when dry, containing small limonite concretions	3
Reddish-tinted clay, very hard when dry, becoming sandy at base	3
Reddish fine stratified sand	3
Gray stratified sand, coarser than the overlying layer	3
Concealed to water level	7
	19

Old Grandglaise, Jackson County.—The site of Old Grandglaise is on White River, a few miles northeast of the present village of Grandglaise. The section exposed in the right bank of the river at this place is as follows:

Section on White River at the site of Old Grandglaise, Jackson County.

Soil and Pleistocene alluvium:	Feet.
White soil	0.5
White clay, very plastic when wet	4.0
Stratified white, very argillaceous sand or sandy clay, containing great numbers of irregular concretions of calcium carbonate	10.0
	14.5

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Colona, Woodruff County.—In a cut of the Chicago, Rock Island & Pacific Railway, south of Colona (2½ miles south of Grays), Woodruff County, the following section is exposed:

Section in cut of Chicago, Rock Island & Pacific Railway near Colona, Woodruff County.

Soil and Pleistocene alluvium:	Feet.
Soil	1.0
Reddish to yellowish argillaceous loam, containing limonite concretions	2.5
White sandy clay, grading downward into harsh reddish sand, which in turn grades downward into soft purplish sand	10.0
	13.5

Augusta, Woodruff County.—Call[1] has described a section on White River, at Augusta, Woodruff County, which is in substance as follows:

Section on White River at Augusta, Woodruff County.

Soil and Pleistocene alluvium:	Feet.
Fine light-colored siliceous humus	2
Brownish argillaceous sand, slightly indurated above, grading downward into softer, less argillaceous sand	1
Reddish sand with some clay, regularly stratified; contains irregularly disseminated nodules of argillaceous limonite one-fourth to one-half inch in diameter, which become softer and larger and more numerous toward base; forms an overhanging ledge in places	8
White cross-bedded sand, with occasional patches of clay	10
Indurated fine, somewhat reddish sand, with some clay; contains nodules of sandy, argillaceous limonite near the base	2
Bluish-white, irregularly bedded sand, coarser and more argillaceous than the overlying layer; contains scattered, smoothly rounded pebbles of chert and a few pebbles of waterworn sandstone, averaging about 1 inch in diameter; one mass of flint weighing about 3 pounds noted	4
Slightly indurated reddish sand, becoming brown below; the upper surface is irregular	1
White argillaceous sand	2
	30

[1] Call, R. E., The geology of Crowleys Ridge: Arkansas Geol. Survey Ann. Rept. for 1889, vol. 2, pp. 22, 23, 1891.

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Phillips County.—The surface in the northwestern half of Phillips County is strongly rolling, presenting a series of low ridges and intervening valleys, a condition believed to have been produced by the erosion effected by the streams where they descend from the Advance lowland to the Mississippi lowland, which lies 25 or 30 feet lower. Along the western side of Crowleys Ridge in this county is a terrace 1 to 3 miles wide and 30 or 40 feet higher than the creek bottom immediately to the west; the terrace is separated from the ridge on the east and the lowland on the west by well-defined escarpments and probably corresponds in elevation to the low ridges in the northwestern part of the county just described. Occasional gullies and road cuttings reveal the character of the materials composing the low ridges and the terrace.

The following section is revealed in a gully cut in the terrace 1½ miles east of Southland and a short distance west of the foot of the west-facing slope of Crowleys Ridge:

Section in gully 1½ miles east of Southland, Phillips County.

Pleistocene alluvium:	Feet.
Dark stratified argillaceous loam	4
Layers of fine argillaceous sand, each a few inches in thickness, some containing small, earthy concretions of limonite	4
Yellow argillaceous sand	2
	10

Hickory Ridge, one of the series of ridges west of Crowleys Ridge (see p. 27), is capped with dark loam which, at Marvell, is 10 or 12 feet thick, as shown by exposures in roadside gullies; the loam is underlain by fine gray sand.

A gully in the road leading from Trenton to Turner, about 5 miles south of west of Trenton, reveals a 9-foot section in a ridge similar to but smaller than Hickory Ridge.

Section in public road 5 miles south of west of Trenton, Phillips County.

Pleistocene alluvium:	Feet.
Soft dark loam	6
Very fine gray sand	3
	9

Logs of wells.—The most complete data regarding the character and thickness of the Pleistocene alluvium has been afforded by the logs of wells located at various places in the area. The following table contains references to the pages of this report on which logs of wells which penetrate these deposits are given:

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References to logs of wells which penetrate Pleistocene alluvium.

Location.	Owner.	Depth (feet).	Depth (in feet) to Eocene (or Cretaceous).	Page on which log of well is given.
ARKANSAS COUNTY.				
Almyra, 2 miles northwest of (SE. ¼ sec. 21, T. 3 S., R. 4 W.).	H. V. Clutter	150	.....	153
Booty, ½ mile west of (W. ½ SE. ¼ sec. 5, T. 8 S., R. 2 W.).	W. N. Carpenter	163	.....	153
Stuttgart	Stuttgart Water & Electric Light Co.	131.75	.....	151
Stuttgart, 6 miles southwest of (sec. 5, T. 3 S., R. 4 W.).	C. E. Edmund	145	.....	152
Tichnor, 4 miles south of (SW. ¼ sec. 16, T. 7 S., R. 2 W.).	J. M. Satchfield	147	.....	153
Ulm (Prairie County), ¼ mile south of, in Arkansas County (NE. ¼ sec. 6, T. 2 S., R. 4 W.).	Caspar G. Scheiderer, R. D. 3.	110	.....	152
CLAY COUNTY.				
Knobel	St. Louis, Iron Mountain & Southern Ry. Co.	50	.....	162
Knobel, 5 miles east of (NW. ¼ sec. 10, T. 19 N., R. 5 E.).	Knobel Rice Co.	178	.....	163
Piggott	Caraway & Friedenburg	74	.....	163
Do	Patter & Co.	98.5	.....	163
CRAIGHEAD COUNTY.				
Bono, 1 mile north of (NE. ¼ sec. 19, T. 15 N., R. 3 E.).	J. E. Bobbitt	78	.....	171
Gilkeson, 2½ miles southwest of (SE. ¼ sec. 8, T. 13 N., R. 3 E.).	Burke & Cole, Jonesboro	103	.....	171
Gilkeson, 3 miles southeast of (SE. ¼ sec. 9, T. 13 N., R. 3 E.).	C. O. Collins, Jonesboro	113	.....	171
Nettleton	St. Louis, Iron Mountain & Southern Ry. Co.	147	.....	170
Obear, 3½ miles northwest of (NE. ¼ sec. 18, T. 13 N., R. 3 E.).	Gregg & Houghton Land Co.	102	.....	171
CROSS COUNTY.				
Fairoaks	St. Louis & Southwestern Ry. Co.	82	.....	183
Fairoaks, 2½ miles east of	T. A. Norviel	65	.....	183
Hydrick (near) (NW. ¼ sec. 2, T. 9 N., R. 3 E.).	S. A. Clements	75	.....	183
Tilton, 4 miles northeast of (SE. ¼ sec. 11, T. 8 N., R. 1 E.).	Miller & Son	80	.....	183
LAWRENCE COUNTY.				
Alicia	St. Louis, Iron Mountain & Southern Ry. Co.	77	.....	204
Walnut Ridge, 1 mile northeast of (SE. ¼ sec. 25, T. 17 N., R. 13 E.).	S. C. Dowell	177	.....	205
Walnut Ridge, 1½ miles southeast of (NE. ¼ sec. 1, T. 16 N., R. 1 E.).	Robinson & Cornett	81.5	.....	205
LEE COUNTY.				
Marianna	Marianna Light & Power Co.	125	.....	210
Moro, 2¾ miles northwest of (SW. ¼ sec. 32, T. 2 N., R. 1 E.).	S. D. Johnston, Marianna.	195	.....	211
LONOKE COUNTY.				
Carlisle, 1½ miles east of (T. 2 N., R. 7 W.)	Mr. Hubbard	180	.....	218
Carlisle, 1½ miles north of (SW. ¼ sec. 10, T. 2 N., R. 7 W.).	Robert Medendorp	158	.....	218
Carlisle, 3 miles southwest of (sec. 32, T. 2 N., R. 7 W.).	J. H. Sims	131	.....	219
Carlisle, 4½ miles southwest of (W. ½ NW. ¼, T. 1 N., R. 7 W.).	W. H. Fuller, Lonoke	140	.....	218
Lonoke	W. Y. Bransford	105	.....	216
Lonoke, 4 miles southeast of (SW. ¼ sec. 33, T. 1 N., R. 8 W.).	B. F. Fromholz	300	200	219
MONROE COUNTY.				
Brinkley	Farrell Light, Heat & Water Co.	565	148	231
Brinkley (near) (sec. 4, T. 3 N., R. 2 W.)	J. D. Edmonds	149.75	.....	231
Brinkley, 1½ miles northwest of (T. 3 N., R. 2 W.).	H. G. Adams	147.5	.....	231

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References to logs of wells which penetrate Pleistocene alluvium—Continued.

Location.	Owner.	Depth (feet).	Depth (in feet) to Eocene (or Cretaceous).	Page on which log of well is given.
PHILLIPS COUNTY.				
Southland	William Russell	135		239
POINSETT COUNTY.				
Waldenburg, 2 miles east of north of (NW. ¼ sec. 18, T. 11 N., R. 2 E.).	Scruggs & Swearengin, Mooreville, Ind.	108.5		246
Waldenburg, 2½ miles southwest of (SE. ¼ sec. 35, T. 11 N., R. 1 E.).	Ellis L. Jackson	101		246
Weiner	St. Louis Southwestern Ry.	101.5		246
Weiner, 1 mile north of (SE. ¼ sec. 21, T. 12 N., R. 2 E.).	S. F. Wells	153.5		246
Weiner, 1½ miles south of (NW. ¼ sec. 17, T. 11 N., R. 2 E.).	Charles Thompson	156		247
Weiner, 3 miles northeast of (SE. ¼ sec. 21, T. 12 N., R. 2 E.).	Frank Housman	75		247
Whitehall, 1½ miles west of (sec. 22, T. 10 N., R. 3 E.).	B. A. McKinny	120		247
PRAIRIE COUNTY.				
Des Arc	Peter Deforest	78		252
Des Arc	J. W. Petty	72		252
Devall Bluff, 3½ miles west of (T. 2 N., R. 5 W.).	Thomas Bros	179	176?	253
Hazen, 2 miles southeast of (T. 2 N., R. 5 W.).	Mr. Avery	176		253
ST. FRANCIS COUNTY.				
Wheetley (near) (average log of 9 wells in Tps. 3 and 4 N., R. 1 W.).	A. Boysen & Sons	145		265
Wheetley (near) (sec. 26, T. 4 N., R. 1 W.)	C. E. Patt	186	185?	266
Zent (Monroe County), northeast of, in St. Francis County (SW. ¼ sec. 5, T. 4 N., R. 1 W.).	The Luhallis Co	175		266
Zent (Monroe County), northeast of, in St. Francis County (SW. ¼ sec. 6, T. 4 N., R. 1 W.).	do	155.6	153?	266
Zent (Monroe County), northeast of, in St. Francis County (SE. ¼ sec. 6, T. 4 N., R. 1 W.).	do	147	146	266
Zent (Monroe County), northeast of, in St. Francis County (SE. ¼ sec. 6, T. 4 N., R. 1 W.).	do	462	145	267
Zent (Monroe County), east of, in St. Francis County (SW. ¼ sec. 8, T. 4 N., R. 1 W.).	Norton Bros., Brinkley	180.8	180?	267
Zent (Monroe County), 1½ miles northeast of, in St. Francis County (W. ½ sec. 6, T. 4 N., R. 1 W.).	Mr. Oliphant	125		267
Zent (Monroe County), east of, in St. Francis County (S. ½ sec. 3, T. 4 N., R. 1 W.).	C. E. Barber	151	149?	267
WOODRUFF COUNTY.				
Hunter, southeast of (sec. 34, T. 5 N., R. 1 W.).	Hunter Land & Rice Co. (well No. 1).	127		277
Hunter, southeast of (sec. 34, T. 5 N., R. 1 W.).	Hunter Land & Rice Co. (well No. 2).	156	155?	277
Hunter, 1½ miles southwest of (sec. 21, T. 5 N., R. 1 W.).	H. L. Baker	108		277

CORRELATION.

The Pleistocene alluvium of eastern and northeastern Arkansas is younger than the loess of Crowleys Ridge and is older than the Recent alluvium. If the main body of the loess was deposited during the time of the Iowan ice invasion (see quotation from Chamberlin and Salisbury on p. 112), then the Pleistocene alluvium was deposited subsequent to that invasion; if the loess was deposited during the

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Peorian interglacial stage, which succeeded the Iowan invasion, the Pleistocene alluvium dates from a still later time. Probably most of Pleistocene time subsequent to the Peorian interglacial stage is represented by the Pleistocene alluvial deposits of this area.

RECENT SERIES.

The Recent deposits of eastern and northeastern Arkansas consist mainly of alluvial silts, loams, clays, sands, and gravels; these materials immediately underlie the surface in the flood plains of the streams and rest upon similar deposits of Pleistocene age, except locally along the borders of the uplands where the Recent deposits rest upon Eocene or Cretaceous strata or at a few places upon Paleozoic rocks.

In the Advance lowland the areal distribution and the thickness of the Recent deposits are less than in the Mississippi lowland. The thickness is determined by the depth to which the streams have scoured as they have meandered back and forth across their flood plains. The maximum depth of scour of Arkansas River, the largest stream of the Advance lowland, is probably not greater than 75 feet below the general level of the flood plain. The depth of scour of the other smaller streams of the area is proportionately less, the minimum being that of small creeks which cut only a few feet below their flood plains.

In the Mississippi lowland the Recent and Pleistocene alluvial deposits have not been clearly differentiated. If Mississippi River has in Recent time meandered entirely across the lowland between Crowleys Ridge and the Chickasaw Bluffs, then the surface deposits are all of Recent age. But even if this stream has not covered the entire lowland much of the area not thus occupied has been covered by St. Francis and Little rivers in their meanderings.

Certain small areas in the Mississippi lowland which lie slightly higher than the general level of the lowland are considered probable remnants of Pleistocene deposits. One of these is Sikeston Ridge or Big Prairie, a narrow, low ridge which extends southward from south of Lake St. John in Scott County, Mo., to New Madrid, New Madrid County, Mo.; another, a low ridge which extends with several interruptions from the southern part of Stoddard County, Mo., a little west of south in a slightly sinuous course through Dunklin County, Mo., into Mississippi County, Ark., is known in its various parts, named in order from north to south, as Rosebriar Prairie, West Prairie, Grand Prairie, and Big Lake Highlands. The meaning of these elevations is rendered obscure because of the fact that changes in level accompanying earthquake shocks have taken place in the area.

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Mississippi River is at present scouring its channel 100 to 130 feet below the general level of the Mississippi lowland, and the Recent alluvial deposits are therefore at least 100 to 130 feet thick over a part of the area. The materials intervening between the lower limit of scour of the present streams of the lowland and the underlying Eocene deposits are of Pleistocene age.

UNDIFFERENTIATED QUATERNARY ALLUVIUM.

Owing to the difficulty in differentiating the Pleistocene and Recent alluvium in the Mississippi lowland and in certain parts of the Advance lowland, it has been necessary in the interpretation of the logs of numerous wells to class the alluvial deposits as undifferentiated Quaternary alluvium. A list of such wells with references to the pages on which the logs are published is given in the following table:

References to logs of wells which penetrate undifferentiated Quaternary alluvium.

Location.	Owner.	Depth (feet).	Depth (in feet) to Eocene or other older rocks.	Page on which log of well is given.
CRITTENDEN COUNTY.				
Turrell	Baker Lumber Co	864	182	175
CROSS COUNTY.				
Parkin	Northern Ohio Cooperage & Lumber Co.	597	.....	182
Cherry Valley, 5 miles east of	Mr. Smith	230	165	183
GREENE COUNTY.				
Beech Grove, 3½ miles north of (SE. ¼ NE. ¼ sec. 11, T. 18 N., R. 4 E.).	Joe Canfee, Lafe	30	.....	189
JACKSON COUNTY.				
Newport, 1 mile southwest of (oil-prospecting well).	.....	1,000	105	197
JEFFERSON COUNTY.				
Wabbaseka, 5 miles east of (NW. ¼ sec. 17, T. 4 S., R. 7 W.).	John Ingram, sr	66	.....	199
MISSISSIPPI COUNTY.				
Ashport Bend, 9 or 10 miles above Osceola	United States Government well No. 1.	164	136.5	227
Do	United States Government well No. 2.	110	.....	227
Do	United States Government well No. 3.	166	146	227
Do	United States Government well No. 4.	168	140	227
Blytheville, 2 miles west of	Chicago Mill & Lumber Co	520	140?	225
Burdette	Three States Lumber Co	1,495.5	123?	226
PHILLIPS COUNTY.				
Helena, 3 miles southeast of	American Cooperage Co	575	160	227
Helena	Mississippi River Commission boring.	206.4	162.3	227

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References to logs of wells which penetrate undifferentiated Quaternary alluvium—Continued.

Location.	Owner.	Depth (feet).	Depth (in feet) to Eocene or other older rocks.	Page on which log of well is given.
POINSETT COUNTY.				
Harrisburg		185	40	245
Harrisburg, 11 miles northeast of	C. Ripley	42	.....	245
Marked Tree	Chapman & Dewey Lumber Co.	398	220	245
PULASKI COUNTY.				
Argenta (at site of new shops)	St. Louis, Iron Mountain & Southern Ry. Co.	80	.....	259
Argenta (well No. 1 in group of 8 wells)	.....do	80	.....	259
Argenta (well No. 4 in group of 8 wells)	.....do	80	.....	259
Jacksonville	A. J. McBride	82	70	259
Jacksonville, ½ mile south of	S. Taylor	24	.....	259
WHITE COUNTY.				
Bald Knob	St. Louis, Iron Mountain & Southern Ry. Co.	225	317	272
Higginson	.....do	62.5	.....	272
WOODRUFF COUNTY.				
Augusta		900	145	276

GEOLOGIC HISTORY.

Deposition of Paleozoic sediments.—For the purpose of this report the history of the events leading up to the present geologic conditions of the Mississippi embayment may be assumed to have begun with the deposition of the Paleozoic rocks which outcrop around the rim of the embayment and which form the basement on which the deposits of the Coastal Plain rest.

The deposition of the Paleozoic rocks began in an intercontinental sea in Cambrian time and continued with certain interruptions, a detailed account of which is outside the province of this report, at least until late Carboniferous time.

Post-Paleozoic erosion interval.—The long period of Paleozoic deposition was brought to a close by a general elevation of the region, land appearing where inland seas had previously existed. Then began a long cycle of erosion, indicated by the total absence of deposits of Triassic and Jurassic age, and, so far as known, of Lower Cretaceous age.

Depression in Lower Cretaceous time.—During Lower Cretaceous time areas both east and west of the present Mississippi embayment, and probably the embayment itself to some extent, were depressed, as indicated by the presence of deposits of Lower Cretaceous age in eastern Alabama and in southwestern Arkansas. Although no strata of this age outcrop in the Mississippi embayment, such deposits possibly exist deeply buried beneath younger formations in the south-central portion of the area.

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Depression and deposition in Upper Cretaceous time.—During Upper Cretaceous time an area coinciding approximately with the present Mississippi embayment was depressed, probably by downward warping, accompanied by more or less faulting, and was covered by marine waters, which advanced across the area from an open sea on the south. This depression is indicated by the strata of Upper Cretaceous age penetrated in a deep well boring at Memphis, Tenn., and by strata which outcrop along the eastern limb of the embayment as far north as the southern part of Illinois, and which are present at certain places along the western limb of the embayment. The Upper Cretaceous deposits consist of sands, clays, and marls formed as the result of the transportation of materials into the sea by streams flowing from the areas of land surrounding the submerged tract on the west, north, and east. In the central part of the embayment the deposits are more than 1,300 feet in aggregate thickness, and are believed to constitute a conformable series.

Uplift and erosion between the Cretaceous and Eocene.—After the deposition of the Upper Cretaceous series the submerged area was elevated above sea level and subjected to erosion. How great a thickness of strata was removed while land prevailed is not known, but from the approximate correspondence in the stratigraphic position of the eroded Upper Cretaceous surface throughout a vast extent of country in the Atlantic and Gulf Coastal Plain the land was probably reduced nearly to a peneplain. The great importance of this erosion interval is shown by the difference in the paleontologic characters of the upper part of the Upper Cretaceous series and the lower part of the overlying Eocene series, few, if any, of the contained molluscan species being common to the two series. The contact between the two series does not appear at the surface within the area under consideration, but is well exposed at many places in Alabama and Mississippi, and its presence in the vicinity of Little Rock, Ark., is indicated by the paleontologic differences already stated.

Depression and deposition in Eocene time.—The erosion interval succeeding the deposition of the Upper Cretaceous series was brought to a close by a depression of the area which submerged a tract probably corresponding in extent nearly to the present Mississippi embayment, though perhaps somewhat more contracted at the northern extremity and along the eastern side in Mississippi, Tennessee, and Kentucky. The depression was accompanied by renewed deposition which, with two important interruptions, and perhaps other minor interruptions, continued through Eocene time and produced in ascending order the Midway, Wilcox, Claiborne, and Jackson formations, the aggregate thickness of which amounts to between 1,000 and 1,500 feet.

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The Midway formation, where typically developed, consists of limestones, calcareous sands, and clays, of marine origin, which show that true marine conditions existed in the southern and central parts of the submerged area at least as far north as the latitude of Newport, Jackson County, Ark. These marine materials merge northward into argillaceous beds of shallow-water origin, which in Tennessee and Kentucky are known as the Porters Creek clay.

The contact between the Midway and Wilcox formations is not exposed in northeastern Arkansas, but Berry[1] has published paleontologic evidence of an unconformity between the two formations in the Mississippi embayment, indicating an important uplift accompanied by erosion.

The Wilcox formation, where exposed in Crowleys Ridge from Craighead northward and also in Mississippi, and deposits of Wilcox age in the Lagrange formation of Tennessee and Kentucky consist of irregularly bedded sands and clays; lignite is common in the formation and in places is segregated into beds; fossil leaves have been collected at numerous places in Mississippi, Tennessee, and Kentucky and at three places in Arkansas. Locally in Crowleys Ridge the sands are indurated to sandstones and quartzites. These characters may perhaps be interpreted to mean that the terrane is a complex of shallow-marine, swamp, and alluvial deposits.

Deposition of the Wilcox formation was followed by uplift which produced a land surface and erosion probably throughout the whole of the embayment. This sequence of events is indicated by the absence of deposits representing the lower part of the Claiborne as developed in Alabama, Louisiana, and east Texas. In upper Claiborne time, however, the area was again depressed and deposition was resumed. The depression probably affected the southern part of the Mississippi embayment more than the northern part, for deposits of the Claiborne formation are not known to extend farther north than Poinsett County, Ark. The northern part of the embayment may have been above water and subjected to erosion. The Claiborne formation in Crowleys Ridge is similar in general lithologic character to the Wilcox formation, but shows a slightly nearer approach to a true marine deposit, as indicated by more massive bedding, particularly in the upper part of the terrane. During Claiborne time subsidence was gaining slightly on sedimentation, and this advantage continued into Jackson time, though, as Berry has shown in the paper just cited,[1] there is evidence of temporary emergence and erosion at the close of the Claiborne.

The Jackson formation consists of sands, clays, and marls of shallow-sea origin. The prevalence of marine conditions during

[1] Berry, E. W., Erosion intervals in the Eocene of the Mississippi embayment: U. S. Geol. Survey Prof. Paper 95, pp. 73–82, 1915 (Prof. Paper 95–F).

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the time of deposition of these materials is indicated by the presence in the formation of the remains of mollusks and foraminifera which inhabited shallow seas. During this period also the northern part of the embayment was probably above sea level, for the Jackson formation has been recognized only as far north as the latitude of St. Francis County, Ark.

Post-Eocene erosion.—Succeeding the deposition of the Eocene series, the Mississippi embayment was again elevated above sea level and the upward movement was probably accompanied by a slight tilting toward the south. Erosion was resumed and probably continued until near the close of Tertiary time; that is, during all of Oligocene, Miocene, and a part of Pliocene time; the streams which drained the emerged area attacked the exposed portions of the Eocene strata and began transporting the materials to the sea, which had retreated southward beyond the limits of the embayment area.

The arrangement of the drainage during this erosion interval is not known, but doubtless a large stream corresponding to the present Mississippi River crossed the area, and this stream was probably joined by an ancient Ohio River somewhere in the Mississippi embayment. Streams corresponding to White and Arkansas rivers doubtless existed.

The erosive action of the streams during this period probably resulted in the removal of a relatively large amount of material from the land, which was not reduced to base level, as shown by the irregularities of the surface upon which the next succeeding formation, the Lafayette, was laid down.

Deposition of the Lafayette formation.—The period of land degradation which followed the deposition of the Eocene series was succeeded, probably during late Pliocene time, by a relatively short period of deposition, during which the Lafayette formation, a terrane composed of irregularly bedded sands and gravels, was laid down. The conditions under which this formation was produced were peculiar and are not thoroughly understood. The available facts, however, appear to justify certain deductions.

The materials were transported from an elevated area in which erosion was active and the transporting power of the streams great. The embayment area must have been considerably lower than this elevated tract, and the gradients of the streams were greatly reduced where they passed from the higher to the lower country; the transporting power of the currents was lessened as a result of the lowering of the gradients, and much of the material carried in suspension or rolled along the stream beds was left stranded along the valley bottoms and lower slopes. Since the gravel deposits are composed chiefly of pebbles and cobbles of chert which range from subangular to only partly waterworn, it is evident that they have been transported

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no great distance, and their source was doubtless the Paleozoic rocks, which are composed in part of cherty limestones and outcrop adjacent to the Mississippi embayment on the west, north, and east. A very small proportion of the gravels consists of small, smoothly rounded quartz pebbles which appear to have been transported a long distance; their history is more complex and is less understood than is that of the chert pebbles and cobbles. The gravels and sands doubtless originally covered much if not all the embayment area.

The chief difficulty in attempting to explain the origin of the deposits of sand and gravel is the fact that the base of the gravel deposits lies at various vertical positions from below the level of the Mississippi lowland to 80 or 100 feet above that datum plane. If the materials were deposited by streams meandering across depositional plains, it would seem that the surface upon which the heavy gravels were laid down would have been reduced to an approximate plain by the lateral cutting of the shifting currents. However, it is probable that the sequence of events was more complicated than can easily be determined from the remnants of the formation available for study. A series of successively younger and lower terraces might account for the observed distribution of the gravels; or the gradual aggradation of valleys permitting the streams to meander over successively higher parts of the adjacent hills might also account for the present position of the gravels.

Post-Lafayette erosion interval.—After the deposition of the Lafayette formation erosion was resumed, either because the streams ceased to carry great loads of coarse material or because there was a general uplift of the area; the resulting dissection produced a surface relief amounting to 100 feet or more.

The arrangement of the drainage during this period of erosion is not known, but doubtless streams existed corresponding to Mississippi, Ohio, White, and Arkansas rivers.

Deposition of the loess.—The erosion interval which succeeded the deposition of the Lafayette formation continued well into Pleistocene time, probably until the second (Kansan) or third (Illinoisan) ice invasion of the Pleistocene epoch, at which time continued erosion was prevented, at least over parts of the area, by deposition of the loess (some of which may be older than the Iowan) upon the sands and gravels of the Lafayette formation.

The loess as it exists to-day is believed to be only a fractional part of that originally deposited, much of it having been since eroded away. The material is now found capping Crowleys Ridge, except in a few places in northern Arkansas and southern Missouri, where it has been eroded from the crest of the ridge; east of the Mississippi lowland the loess occurs in a belt 5 to 25 miles or more in width, paralleling the Chickasaw Bluffs and extending from southern

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Illinois southward through Kentucky, Tennessee, and Mississippi to Louisiana; along the western margin of the Mississippi embayment in Arkansas fragmentary remnants of yellowish, reddish, and brownish loam, which probably represent the loess, are found capping the Grandglaise terrace in places and resting upon the east-facing slopes of the hills of the Ozark province. How much of the intervening areas now occupied by the Advance lowland and the Mississippi lowland were originally covered by loess is not known, but doubtless the areal extent of the deposit was much greater than at present.

Several explanations have been given to account for the formation of the loess. These have been summed up by Chamberlin and Salisbury[1] as follows:

> By the aqueous hypothesis the loess is assigned to direct deposition by rivers, or their lakelike expansions. To make this possible it is necessary to suppose that the waters stood at elevations 200 to 600 feet higher than now relative to adjacent surfaces, in the Mississippi Basin. This involves difficulties that have never been satisfactorily met. Furthermore, if the waters of rivers or their lake-like expansions were high enough to cover the areas overspread by loess, it is not clear that there could have been an appropriate habitat for the land fauna of the time.
>
> Under the eolian hypothesis, or at least one phase of it, the river flats are supposed to have supplied the material of the loess, which was whipped up by the winds and redeposited on the adjacent uplands. The rivers are thus made essential factors in the distribution, though not the direct agents of deposition. This hypothesis seems on the whole to best fit the phenomena of the larger part of the upland loess of the Mississippi Basin. The constituents of the loess, which appear to have come from the glacial drift, were derived largely from the deposits made by glacial waters or from later flood plain silts derived from the glacial formations, but it is probable that some of the loess was derived from glacial drift directly before it became clothed with vegetation.

In places in Crowleys Ridge the basal portion of the loess shows some evidence of stratification and generally the stratified materials are sandy or argillaceous. The bulk of the loess, however, is massive, though banding is discernible in the more complete exposures. The remains of land shells are numerous in the loess from St. Francis County to the southern extremity of the ridge. One fresh-water form, Sphærium sp.?, has been found associated with land shells at two localities east of Forrest City, in St. Francis County. (See p. 108.) Although locally the basal portion of the loess may have been deposited in ponds or small lakes, the objections to the aqueous hypothesis to account for the origin of the deposits heretofore advanced, seem in the main to be applicable here. Of the explanations that have been offered, the modified eolian hypothesis described in the last paragraph of the quotation just given seems to be most in accord with the known facts. According to this theory fine silts derived

[1] Chamberlin, T. C., and Salisbury, R. D., A college textbook of geology, pp. 889–890, 1909.

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from the glacial drift were transported southward by the streams and at flood stages were deposited on the flood plains; these materials, when subsequently dried, were lifted by the winds and spread upon the adjacent slopes and uplands. As the materials accumulated the shells of land mollusks were entombed and in places preserved; occasional slight changes in the prevailing character of the materials transported by the streams or in the character or condition of the vegetable growth resulted in the banding observed in the deposits.

The deposits were spread over a considerable part of the area now occupied by the Advance and Mississippi lowlands and have been subsequently largely removed by the extensive lateral cutting effected by the streams of late Pleistocene and Recent time. The effective deposition of the loess probably ceased before or during the Peorian interglacial stage.

Erosion of the great troughs west and east of Crowleys Ridge and deposition of Pleistocene alluvium.—The distribution of the drainage in the Mississippi embayment during the time of deposition of the loess has not been definitely determined, but the close of that time found Mississippi and Ohio rivers following independent courses southward through the Mississippi embayment, the former west of and the latter east of Crowleys Ridge; the two joined south of the present southern extremity of the ridge. If it be true that the loess was deposited by wind action, this fact would seem to preclude the possibility of the Mississippi having found its way west of Crowleys Ridge during the time of that deposition, because of the topographic obstacles that must have intervened. This arrangement of the drainage is believed, therefore, to date back into the Tertiary period. Mississippi River, as it existed in southeastern Missouri immediately after the deposition of the loess, appears to have been a superimposed stream, which also tends to confirm this view.

The succession of geologic events which transpired in the northern part of the Mississippi embayment from the close of loess deposition to the present time has been determined and described by Marbut.[1]

The brief account which follows is in substance the interpretation of Marbut with the application of his interpretation extended to cover the whole of the embayment, and with such modifications and additions as the conditions existing south of Missouri make necessary.

Shortly subsequent to the close of the deposition of the loess the embayment area was elevated, probably not less than 100 feet above its present position with reference to sea level. Stream erosion was accelerated and the rivers quickly entrenched themselves, their lower

[1] Marbut, C. F., The evolution of the northern part of the lowlands of southeastern Missouri: Missouri Univ. Studies, vol. 1, No. 3, 63 pp., 7 pls., 1902.

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limit of scour reaching a level corresponding to the base of the present alluvium of the lowlands. At that time Mississippi River did not follow its present course, but flowed southwestward from Cape Girardeau, Cape Girardeau County, Mo., northwest of the present site of Benton Ridge, and northwest and west of Crowleys Ridge. Ohio River flowed southwestward east of Crowleys Ridge and joined the Mississippi south of the present southern extremity of the ridge.

From Cape Girardeau to Mingo, Stoddard County, Mo., the Mississippi soon found both its downward and lateral cutting hindered by hard Paleozoic rocks, which formed its bed and sides. From Mingo southward through Arkansas the river was entrenched in unconsolidated deposits of the Coastal Plain and quickly reached grade; thereafter the stream meandered, its energies were expended in lateral cutting, and a great, broad trough was, geologically speaking, quickly scoured out. The bottom of this trough was 125 to 200 feet below the present level of the Advance lowland, and the geographic extent coincided with this lowland. The materials removed belonged in descending order to the loess, the Lafayette formation, and to the Eocene and Cretaceous.

Contemporaneous with the lateral cutting the river was redepositing sands, clays, and gravels on the plain across which it meandered, so that as the trough was widened it was refilled with alluvial deposits nearly or quite to the level marked by the present Advance lowland. There is some evidence that before the river was finally diverted from its course west of Crowleys Ridge a slight increase in the thickness of the alluvial deposits was caused by a depression of the area amounting to several feet; the same result might have been accomplished, however, by an increase in the amount of materials carried in suspension by the currents. In the work of cutting and refilling this trough the Mississippi was aided to some extent by Arkansas and White rivers, which entered the valley from the Ozark province.

The ever-broadening flood plains of the Mississippi and its assistants, White and Arkansas rivers, were periodically overflowed by flood waters which spread back across the broad flat tracts from the main channels and deposited their burdens of fine silt, producing the layer of compact, silty clay which nearly everywhere forms the uppermost part of the Pleistocene alluvial deposits. At many places on the level interstream tracts the conditions were favorable for the precipitation of iron oxide as limonite, which took the form of small, impure concretions, or a sort of bog iron ore; these concretions characterize the so-called buckshot soils of the area.

Contemporaneous with the dissection and partial refilling of the great valley west of Crowleys Ridge, Ohio River was accomplishing analogous results east of the ridge. After leaving the Paleozoic rocks above Cairo, Ill., the Ohio encountered only unconsolidated mate-

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rials and quickly scoured out and partly aggraded a trough nearly coextensive with the present Mississippi lowland. Crowleys Ridge stood between these two great valleys and remains to the present time a remnant of and an index to the deposits that filled the lowlands previous to the cutting of the two great valleys. The flood plain built by the Ohio was similar to that formed by the Mississippi, except that in the northern part of the embayment, the plain of the Ohio stood a few feet lower than that of the Mississippi. Only small remnants of this old Ohio River flood plain testify to its former existence.

Captures of Mississippi River by Ohio River.—At this stage in the evolution of the embayment area an event transpired which caused a radical change in the arrangement of the drainage. A small tributary of Ohio River, the source of which was in the highland that then connected Benton Ridge, Mo., and the northern extremity of Crowleys Ridge, had been gradually pushing its headwaters northward toward Mississippi River. The fact that Ohio River flowed at a lower level than Mississippi River made it possible for this small tributary stream to perform a remarkable feat. Omitting numerous interesting details described by Marbut, the stream cut its headwaters back until one of them finally tapped the Mississippi somewhere in the vicinity of the present village of Delta, and the waters of that great stream, accepting the advantage offered by this steeper and shorter route southward, followed the small valley and quickly carved out a channel suitable to their greater needs. The Mississippi thus abandoned its course west of Crowleys Ridge and joined the Ohio, probably a short distance south of the present site of New Madrid.

The Mississippi occupied this new course until by lateral cutting it produced the gap which now separates Benton and Crowleys ridges, and which forms a part of the Morehouse lowland of Marbut. In the meantime another small tributary of Ohio River had been pushing its headwaters northward from the vicinity of Commerce, Scott County, Mo., toward Grays Point (Graysboro), also in Scott County, and eventually this stream succeeded in tapping the Mississippi and diverting its waters southward to join the Ohio somewhere not far from its present junction at Cairo. Thus twice in a relatively short period this great major stream was diverted from its former course by streams of insignificant size.

After the first capture of the Mississippi, the waters of Castor and St. Francis rivers, former tributaries of the Mississippi, continued to flow west of Crowleys Ridge. Since that time both of these streams have been diverted through Crowleys Ridge by small streams working backward into the ridge in the same manner that the captures of the Mississippi were effected. L'Anguille River, one of the consequent

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ECONOMIC USES.

The surface waters of the area are of suitable quality for use boiler supplies, for irrigation, and for stock. The waters of streams are suitable for domestic and municipal water supplies, cept those that are polluted or heavily loaded with sediment. ground waters unobjectionable in these respects are available in m of the area, the surface waters have been adopted only to sm extent for domestic and municipal use. Where it is impractic to obtain adequate supplies of underground water, as at Little R which is on the boundary between the Ozark province and the C Coastal Plain, proper filtration will render the surface waters p ble. The city water supplies of Little Rock, Pulaski County; N port, Jackson County; and Luxora, Mississippi County, are obta from Arkansas, White, and Mississippi rivers, respectively.

GROUND WATERS.

SOURCE.

The strata which underlie northeastern Arkansas are satur with water below a level, known as the water table, which ra from the surface to a depth of 100 feet or more. The water table deepest in Crowleys Ridge and shallowest in the lowlands east west of that ridge; in the swamps it lies continuously or inter tently above the surface of the ground. The water table does occupy a fixed position at any given place but continually fluctu being highest at the end of a long period of precipitation and lo at the end of a long drought.

Although saturated to the level of the water table the var strata do not yield their contained waters to wells with equal re ness. The waters in the more compact layers are so comple locked within the fine interstices as to be practically unobtain Only the more porous sands and gravels yield their waters rea and in large quantities; it is to strata composed of these mate that the term water-bearing beds is commonly applied, and t are the strata that the well driller seeks to reach with the drill.

The location and depth of wells concerning which detailed in mation has been obtained are indicated in Plate XI.

The greater part of the ground water of northeastern Arkansa derived from rainfall within the borders of the area. The ca ment area for the waters of the flowing wells, east of Crowl Ridge, in the Mississippi lowland, however, lies east of Mississi River in Mississippi, Tennessee, and Kentucky. There is prob also a general, though extremely slow movement of the gro waters from the head of the Mississippi embayment in Miss

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southward toward the Gulf. Some water may also leak from the Paleozoic basement rocks to the unconsolidated deposits of the Gulf Coastal Plain, particularly near the outer border of the embayment area.

At certain places elsewhere in the Atlantic and Gulf Coastal Plain waters absorbed by the strata at the time of their deposition on the bottom of the ocean have remained locked in the interstices of the materials to the present time, and unless such waters have been greatly modified by subsequent mixture with waters from other sources, their resemblance to sea water renders it possible for the chemist to detect their marine origin. There is, however, no evidence to show that any of the underground waters of northeastern Arkansas are originally included sea waters, and it may be repeated that nearly all the ground water now recovered by wells in that area is derived from rainfall within the area itself.

DISPOSAL.

Van Hise[1] has estimated that at least 99 per cent of the meteoric waters that enter the earth return to the surface sooner or later, the remaining 1 per cent or less entering into chemical combination with minerals. A large part of the ground water gradually returns to the surface by capillary attraction and is evaporated; a large part is taken up by the roots of plants and is eventually evaporated; and a large part emerges at the surface as springs and flows away in streams. In an area underlain by strata that are inclined slightly toward the ocean, as in the Atlantic and Gulf Coastal Plain, there is probably a constant though extremely slow movement of the ground waters in the direction of the coast, so that a large proportion of these waters may reach the ocean by this course. In some thickly settled regions, where enough water is removed from the earth by wells to lower the water table appreciably, the problem of conserving the ground waters becomes important.

QUANTITY.

In the part of Arkansas included in the Mississippi embayment ground waters are abundant except in certain locally unfavorable areas. The depth to water-bearing strata of large capacity differs, but throughout the lowlands which comprise the greater part of the area, large quantities of water are obtained at depths of 50 to 200 feet. Many wells in the rice-growing areas are pumped at rates between 1,000 and 3,000 gallons a minute, or even more, but reports so far received indicate no appreciable decrease in the underground supplies.

[1] Van Hise, C. R., Treatise on metamorphism: U. S. Geol. Survey Mon. 47, p. 156, 1904.

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STRATIGRAPHIC DISTRIBUTION.

CRETACEOUS DEPOSITS.

The beds of porous sand which partly compose the buried Cretaceous deposits of the area constitute an important, though largely undeveloped, source of artesian water. The depth to the Cretaceous deposits has not been determined precisely at any place, but according to the interpretation of the record of a well at Memphis, Tenn., strata of this age were first encountered there at a depth of 1,135 feet. In northeastern Arkansas flowing wells that doubtless tap water-bearing beds of Cretaceous age are in use at Blytheville, Mississippi County (depth 1,448 feet); Burdette, Mississippi County (depth, 1,495.5 feet); Wilson, Mississippi County (depth, 1,567 feet); and Marked Tree, Poinsett County (depth, 2,007 feet). Nonflowing wells that tap beds of this age are located at Jonesboro, Craighead County (1,214 and 1,265 feet deep, respectively), and at Newport, Jackson County (depth to Paleozoic rocks, 655 feet).

TERTIARY DEPOSITS.

EOCENE STRATA.

Basal Eocene strata, which outcrop in the Grandglaise terrace along the western border of the Mississippi embayment, have been correlated with the Midway formation, and the Eocene deposits that compose the core of Crowleys Ridge have been roughly separated in ascending order into the Wilcox, Claiborne, and Jackson formations. With these exceptions, the deposits of Eocene age which underlie practically all eastern and northeastern Arkansas, beneath the Pleistocene and Recent alluvial deposits, remain undifferentiated, and until a large amount of accurate well data has been obtained must be treated as a unit. A few wells scattered over the area have demonstrated that these buried Eocene deposits contain important water-bearing beds and constitute a possible source of artesian water, which is still largely undeveloped.

The Eocene strata dip slightly away from the rim of the Mississippi embayment, and their numerous interbedded layers of porous sand contain waters under sufficient hydrostatic pressure to bring them within easy reach of ordinary force or suction pumps, and perhaps in places in the Mississippi lowland, to produce flows at the surface. Deep wells have not been drilled in sufficient number to determine the vertical positions of the more extensive water-bearing portions of the deposits. Some wells have shown the presence of thick beds of clay which are economically not water bearing; others have encountered sands which, locally at least, are abundantly water bearing.

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Concerning a few wells, notably certain ones on or near Crowleys Ridge, the probable subdivision of the Eocene to which the water-bearing beds belong can be indicated.

The wells known to tap water-bearing beds in the Eocene deposits are indicated in the tables of well data accompanying the descriptions of the water resources of the various counties. A few of the more important wells will, however, be mentioned here.

At Marked Tree, Poinsett County, there are four wells, 392 to 400 feet in depth (see wells Nos. 4–7, p. 248), which tap a water-bearing bed of Eocene age, probably belonging to the upper part of the Wilcox formation. The water is obtained between the depths 360 and 400 feet and rises within 1½ to 8 feet of the surface. This stratum is an important aquifer, at least locally, since each of the four wells yields enough water to supply the boilers of a large lumber mill.

At Blytheville, Mississippi County, a well 520 feet deep (see well No. 2, p 228) taps a water-bearing sand at a depth of 500 feet; the water rises within 15 feet of the surface, and the yield is sufficient to supply the boilers of a large lumber mill. This stratum is believed to be in the Wilcox formation of the Eocene.

At Turrell, in Crittenden County, gray water-bearing sand, probably belonging to the basal portion of the Wilcox formation, is encountered in the lower 24 feet of an 864-foot well (well No. 5, p. 178); the static head of the well is 12 feet below the surface.

Wells at Wynne, Cross County, 186, 250, and 360 feet deep, respectively (wells Nos. 15, 16, 19, p. 184), tap water-bearing beds in Eocene deposits, probably belonging to the Wilcox formation of that series.

At Parkin, in Cross County, two wells, 480 and 597 feet deep, respectively, obtain water from beds of sand believed to belong to the upper part of the Wilcox formation (wells Nos. 9, 10, p. 184). In one well (No. 9) the water rises within 10 feet of the surface, and in another (No. 10) within 12 feet of the surface; each well supplies the boilers of a large mill which manufactures wood products.

Another well which taps a coarse, water-bearing sand, probably belonging to the upper part of the Wilcox formation, is at Earl, Crittenden County (well No. 1, p. 178). It is 474 feet deep, and the water-bearing sand makes up the lower 60 feet of the section; the static head is 14½ feet below the surface.

The municipal water supply of Forrest City, St. Francis County, is obtained from three wells, 425, 425+, and 450 feet in depth, respectively, which at a depth of 400 feet tap a coarse, water-bearing sand probably referable to the upper part of the Wilcox formation; the water rises within 70 feet of the surface (wells Nos. 3, 4, 5, p. 268).

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The municipal water supply of Marianna, Lee County, is taken from two wells, each 619 feet deep (wells Nos. 3, 4, p. 212). Here the source of the water is white sand of Eocene age; the water rises within 60 feet of the surface.

At and near Helena, Phillips County, numerous wells, including those of the city waterworks, tap clean coarse to fine water-bearing sands at depths of 450 to 575 feet; these sands probably belong to the Claiborne formation (wells Nos. 2–6, p. 240). The water, which is soft and of excellent quality for domestic and industrial supplies, rises within 18 to 40 feet of the surface.

A 400-foot well at Barton, Phillips County, taps a water-bearing sand which probably corresponds to that penetrated by the wells at Helena; the static head is 20 feet below the surface and the water is soft (well No. 1, p. 240).

At Brinkley, in Monroe County, the municipal water supply is obtained from a well (565 feet deep), which penetrates a fine, white, water-bearing sand in the lower 68 feet of the section; the static head is 40 feet below the surface (well No. 1, p. 232).

LAFAYETTE FORMATION (PLIOCENE?).

The Lafayette formation is locally water bearing in Crowleys Ridge, where it is tapped by numerous bored and dug wells; the waters belong to the nonartesian class (p. 139) and are used for house and farm supplies. The formation is the source of the waters of many small springs.

QUATERNARY DEPOSITS.

The loess is not an important water-bearing formation because of its close texture and its elevated topographic position.

The Pleistocene alluvium, which underlies the Advance lowland to an estimated maximum depth of 200 feet, is, from an economic standpoint, the most important water-bearing formation in northeastern Arkansas. In the interstream areas the materials immediately underlying the surface almost everywhere are compact, silty clays that are nearly impervious to water and therefore protect the waters below them from surface pollution. The waters are contained chiefly in the fine to coarse sands and gravels which compose the lower one-half to two-thirds of the deposits.

In the Mississippi lowland the coarse sands and gravels of Pleistocene age, which largely compose the basal portion of the Quaternary alluvial deposits also are abundantly water bearing.

The sands and gravels of the Recent alluvium contain abundant water suitable for use in boilers and other industrial operations. In general, these waters are not considered desirable for domestic use

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because of the danger of pollution; where local beds of impervious clay overlie the water-bearing beds, the waters may, however be safely used.

SPRINGS.

Numerous small springs in Crowleys Ridge and in the Grandglaise terrace are used to a small extent as house and farm supplies. In the lowlands seepage springs are common along the stream banks, along the margins of swamps, and at the heads of small branches, but they are of slight importance because of their intermittent character and small yield.

NONARTESIAN WATERS.

DEFINITION AND IMPORTANCE.

The term "nonartesian" is in this report applied to ground waters that are not under sufficient hydrostatic pressure to force them above the containing beds when they are tapped by wells or other excavations. Nonartesian waters are of great economic importance in the Arkansas lowlands because they are used more extensively than those of any other class for domestic and industrial supplies and for irrigation. Their value has become more fully appreciated since their applicability to rice lands has been demonstrated.

The nonartesian waters are contained in the alluvial deposits which underlie the Mississippi lowland and the Advance lowland to depths of 100 to 225 feet. The water table in these deposits ranges in vertical position from the surface to a depth of 65 feet.

Except perhaps locally these waters do not rise at all in wells above the level of the water table or rise only slightly above it. In the tables of well data which accompany the county descriptions the depth to the principal water-bearing bed of most wells is reported as greater than the depth at which the water stands in the wells; but the principal water-bearing bed is generally understood by well owners and drillers to be the coarse, basal sands and gravels which yield their contained waters readily, and the true water table is at a higher level in the finer overlying sands, which are an essential part of the reservoir. The geologic position of the nonartesian waters is graphically represented in *a*, figure 3, p. 142, and *b*, figure 4, p. 143.

METHODS OF DEVELOPMENT.

The nonartesian waters are obtained by means of dug, bored, and driven wells, and are raised by rope and bucket, hand suction or force pumps, windmills, and various types of more powerful steam or gasoline driven pumps. The type of well, its depth and diameter, and the kind of lifting machinery are determined by the purpose to

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which the waters are to be put and the amount of water required. Wells intended to supply municipalities, large factories, and irrigated lands are equipped with powerful machinery, centrifugal pumps and air lifts being most generally used.[1]

ARTESIAN WATERS.

DEFINITION.

The term "artesian" is applied in this report to ground waters that are under sufficient hydrostatic pressure to force them above the level of the containing beds when they are penetrated by wells or other excavations. Thus artesian water does not necessarily overflow, and an artesian well may be either flowing or nonflowing. The significance of the term "artesian" has been discussed by Fuller.[2]

GENERAL CONDITIONS GOVERNING OCCURRENCE.

Fuller's summary[3] of the essentials and secondary factors of artesian flows, which is applicable also to nonflowing artesian waters, is quoted below:

> The essentials of artesian flows, as recognized by the writer, are as follows:
>
> 1. An adequate source of water supply.
>
> 2. A retaining agent offering more resistance to the passage of water than the well or other opening.
>
> 3. An adequate source of pressure.
>
> The first requisite is not made specific as regards source, because, as has been pointed out, artesian waters are not derived from a single but from a variety of sources. The second requisite—the retaining agent—may be a stratum, a vein or dike wall, a joint, fault, or other fracture plane, a water layer, or some one of a variety of other agents. * * * The pressure, although primarily due to variations in level in the different parts of the artesian system, may be transmitted in so many ways and is subject to so many modifying factors that the postulation of a specific cause is impracticable. * * *
>
> It is believed that the three factors stated in the preceding paragraph are all that can be considered as essential to artesian flows, all other postulated requisites being in reality modifying or accessory rather than essential factors. These secondary factors may be classified as follows:

---

[1] Wilson, H. M., Pumping water for irrigation: U. S. Geol. Survey Water-Supply Paper 1, 57 pp., 1896.

Murphy, E. C., Windmills for irrigation: U. S. Geol. Survey Water-Supply Paper 8, 49 pp., 1897.

Hood, O. P., New tests of certain pumps and water lifts used in irrigation: U. S. Geol. Survey Water-Supply Paper 14, 91 pp., 1898.

Perry, T. O., Experiments with windmills: U. S. Geol. Survey Water-Supply Paper 20, 97 pp., 1899.

These reports can be consulted only in libraries, as the editions have long been exhausted.

[2] Fuller, M. L., Underground-water papers: U. S. Geol. Survey Water-Supply Paper 160, pp. 9–15, 1906.

[3] Fuller, M. L., Summary of the controlling factors of artesian flows: U. S. Geol. Survey Bull. 319, pp. 36, 37, 1908.

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Secondary factors of artesian flows.

I. Hydrostatic factors (relating to pressure and movement):
  1. Factors mainly affecting pressure—
    (*a*) Barometric pressure.
    (*b*) Temperature.
    (*c*) Density.
    (*d*) Rock pressure.
  2. Factors mainly affecting movement—
    (*a*) Porosity.
    (*b*) Size of pores or openings.
    (*c*) Temperature.

II. Geologic factors (relating to reservoir):
  1. Character of reservoir.
  2. Retaining agents.
  3. Structure of reservoir.
  4. Topographic conditions.
  5. Conditions relating to supply—
    (*a*) Catchment conditions.
    (*b*) Condition of underground feed.
  6. Conditions of leakage.

Hydrostatic pressure in ground waters results from various causes, but any set of conditions that produces such pressure may be termed an artesian system. Fuller[1] has illustrated by diagrams several of the more common artesian systems.

CONDITIONS IN THE ADVANCE LOWLAND.

The artesian and nonartesian conditions from north to south in the Advance lowland west of Crowleys Ridge are shown diagrammatically in figure 3. The Eocene and Cretaceous strata which contain the artesian waters are completely covered by Quaternary alluvial deposits (*a*) which contain nonartesian waters. Rain is absorbed by the alluvium chiefly through the sandy surface materials (*c*) forming the broad flood plains of the present streams, but in part through the slightly pervious silty loams and clays (*b*) which immediately underlie the interstream areas. The alluvial deposits are saturated with water below the level of the water table, which lies from a few feet to 65 feet below the surface; the tendency to develop hydrostatic pressure in the water contained in the alluvial deposits produced by their slight southward tilt is overcome by friction and the waters are therefore nonartesian.

The alluvial deposits serve as a catchment area for the water-bearing beds of the underlying Eocene and Cretaceous strata which dip at a greater angle to the southward; the water gains entrance to these beds at the points indicated by the arrows (*h*). In the pervious stratum (*d*) which lies between two relatively impervious strata, the

[1] Fuller, M. L., Summary of the controlling factors of artesian flows: U. S. Geol. Survey Bull. 319, pp. 38–42, 1908.

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only hindrance to the passage of the water down the dip is friction; friction in the bed below the point at which it is tapped by the well produces a certain amount of hydrostatic pressure. In the pervious stratum (*e*) which pinches out down the dip between two relatively impervious strata, hydrostatic pressure is produced by the weight of the confined water. The pervious stratum (*f*) merges down the dip into relatively impervious materials and hydrostatic pressure is produced in the same manner as in stratum (*e*). In the pervious stratum

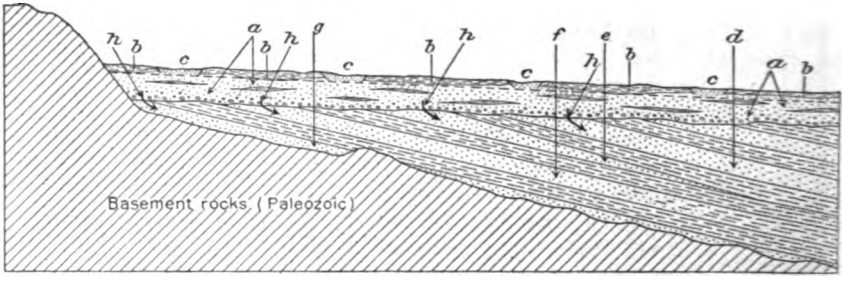

FIGURE 3.—Section to illustrate artesian and nonartesian conditions in the Advance lowland west of Crowleys Ridge, Ark. For explanation see text.

(*g*) the passage of the water down the dip is prevented by an unconformity, and hydrostatic pressure is produced in the same manner as in the two preceding cases.

Although hydrostatic pressure exists in the southward-dipping Cretaceous and Eocene strata of the Advance lowland as represented in figure 3, the conditions, so far as understood and so far as tested, seem to be unfavorable for the development of sufficient pressure to force the water above the surface of the ground.

CONDITIONS IN THE MISSISSIPPI LOWLAND.

In the Mississippi lowland east of Crowleys Ridge the conditions which, when viewed from north to south, appear to be similar to those in the Advance lowland west of the ridge, are modified by a set of east-west conditions favorable to the production of hydrostatic pressure sufficient to cause overflows at the surface in wells 1,000 feet or more in depth. Figure 4 represents these conditions along a line from the vicinity of Lexington, Tenn., westward through Mississippi County, Ark., to Crowleys Ridge, and similar conditions probably exist throughout the greater part of the Mississippi lowland. (See Pl. XI.) This area is underlain beneath 150 to 225 feet of Quaternary alluvial deposits, in descending order, by 2,000 to 3,000 feet or more of Eocene and Cretaceous strata which rise eastward and outcrop in Tennessee and Mississippi at elevations of 400 to 600 feet. On account of the greater elevation of the catchment area and the con-

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sequent greater weight of the waters confined in the inclined strata, greater hydrostatic pressure is developed in the deposits underlying the Mississippi lowland. This is believed to be the explanation of the flows obtained in Mississippi County at Blytheville (depth, 1,448 feet), Burdette (depth, 1,495 feet), and Wilson (depth, 1,567 feet), and in Poinsett County at Marked Tree (depth, 2,007 feet).

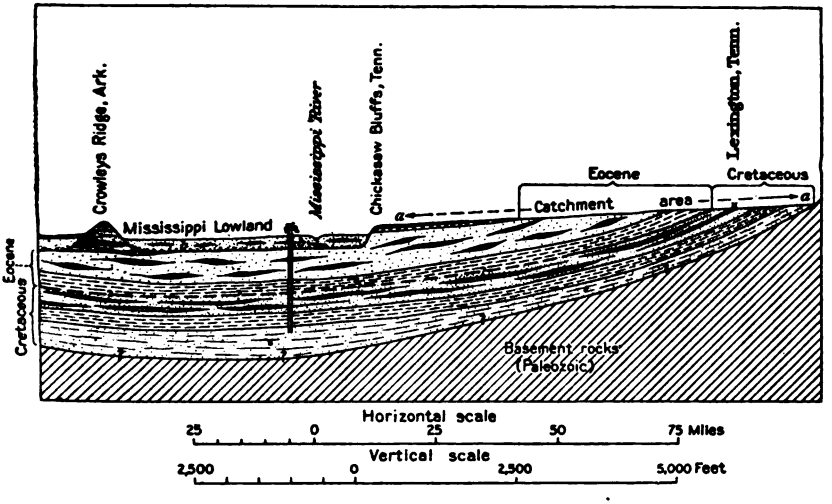

FIGURE 4.—Generalized section to explain the cause of artesian flows in the Mississippi lowland: Water entering the Eocene and Cretaceous deposits in the catchment area *a a* passes down the inclined strata by gravity. Hydrostatic pressure is developed in the several ways explained in figure 3, and because of the greater elevation of the catchment area the pressure is great enough to cause overflows in the Mississippi lowland. *b* is the Quaternary alluvium of the Mississippi Valley.

ECONOMIC USES.

GENERAL USES.

Throughout northeastern Arkansas water for domestic and farm use is obtained chiefly from wells. Except Little Rock, Pulaski County; Newport, Jackson County; and Luxora, Mississippi County; which use the waters of Arkansas, White, and Mississippi rivers, respectively, the towns and cities having municipal waterworks are supplied from wells. Nearly all the manufacturing plants and railroads draw from the same source. The ground waters have been used locally in a small way for irrigating lands devoted to market gardening, but because of the relatively high precipitation the necessity for such irrigation is keenly felt only at occasional intervals. The advantage gained, however, by even distribution of moisture during the growing season would doubtless render profitable the general establishment of pumping plants on garden farms.

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RICE CULTURE.[1]

HISTORY.

Rice has been grown commercially in Arkansas since 1904 and conditions are ideal for the rapid development of the industry. The soils of most of the prairie land in the interstream areas of the Advance lowland between Crowleys Ridge and Arkansas River are peculiarly adapted in composition and distribution to the raising of this cereal, and large quantities of the water necessary for irrigation lie at relatively shallow depths beneath the prairies. For the following account of the beginning of the rice-growing industry in the prairies of Arkansas the authors are indebted to Mr. W. H. Fuller, of Lonoke, the pioneer experimenter who raised the first commercially important crop of rice in the State, and to Mr. E. G. Norton, of Brinkley, who has taken special pains to furnish data from reliable sources.

In August and September, 1896, Mr. Fuller and Mr. H. H. Puryear made a wagon trip from Lonoke southward through Arkansas and Louisiana to the Gulf of Mexico. Eight miles north of Crowley, La., they saw rice fields owned and operated by Abbott Bros., of Crowley. As this was the first rice either of them had seen growing, they spent two days studying the plantations of Abbott Bros. and of W. W. Duson, and became convinced that the conditions under which rice was grown in the prairies of southwestern Louisiana were essentially like those existing in the prairies of Lonoke County, Ark.

After his return to Lonoke, Mr. Fuller made preparations to raise an experimental crop of rice on his farm, 8 miles southeast of Lonoke (in the NW. ¼ sec. 8, T. 1 N., R. 7 W.). He drilled two 4-inch wells, installed a pumping plant, and in the spring of 1897 planted 3 acres in rice. Some of the seed germinated, grew, and headed out, but because of an accident to the pumping plant and consequent failure to apply the necessary amount of water to the crop the grain did not reach maturity. Yet the experiment, so far as it went, was successful, for it demonstrated that the grain, if properly irrigated, could be raised on the prairies of Arkansas.

In 1898 Mr. Fuller moved to Louisiana and engaged in rice culture on the prairies of that State for four seasons; he familiarized himself in a practical way with the methods employed in preparing the soil, planting the seed, irrigating the growing plants, and harvesting the grain; he also learned how wells were drilled and equipped for

[1] Literature relating to rice culture in Arkansas, Louisiana, and Texas:

Bond, Frank, Irrigation of rice on the uplands of Louisiana and Texas: U. S. Dept. Agr. Office Exper. Sta. Bull. 113, 19 pls., 9 figs., pp. 1–57, 1902.

Fuller, M. L., Rice irrigation in southern Louisiana: U. S. Geol. Survey Water-Supply Paper 101, pls. 9–11, figs. 13–15, pp. 82–94, 1904.

Knapp, S. A., Rice culture: U. S. Dept. Agr. Farmers' Bull. 417, 30 pp., 1910.

Bonsteel, J. A., The Crowley silt loam: U. S. Dept. Agr. Bur. Soils Circ. 54, 8 pp., 1912.

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supplying water for irrigation. During 1903, while Mr. Fuller was in Louisiana, 5 acres of rice were grown in Lonoke County by the Johnson Morris family; no detailed information has been obtained concerning this crop.

In the fall of 1903 Mr. Fuller returned to Arkansas, and with the financial backing of citizens of Carlisle and Hazen, he made preparations to raise a crop of rice on a commercial scale. A well was drilled and equipped for pumping on Mr. Fuller's farm, and 70 acres was planted to rice in the spring of 1904; at the end of the season 5,225 bushels were harvested. The total cost of producing this crop, including the cost of drilling and equipping the well, was $3,147, and the crop sold for $1 a bushel. During the same season a branch station of the Arkansas Agricultural Experiment Station was established 1½ miles west of Lonoke, where 750 bushels of rice were raised on 10 acres of land. Rice was also raised during the same season by the Morris family, but no statistics concerning the crop are available.

PRODUCTION.

The completely successful efforts of Mr. Fuller and of the experiment station to raise rice demonstrated beyond question that this cereal could be grown at a profit on the prairies of Arkansas, and the lessons taught by these demonstrations were quickly learned. The rapid development of the rice-growing industry in Arkansas from 1905 to 1914, inclusive, is shown by the following table compiled by the United States Department of Agriculture:

Acreage and production of rice in Arkansas, 1905 to 1914, inclusive.

Year.	Acreage.	Production.	Average per acre.	Year.	Acreage.	Production.	Average per acre.
		Bushels.	*Bushels.*			*Bushels.*	*Bushels.*
1905	460	22,356	48.6	1910	60,000	2,400,000	40
1906	4,240	131,440	31	1911	71,600	2,792,000	39
1907	6,000	222,000	37	1912	90,800	3,405,000	37.5
1908	11,400	467,400	41	1913	104,700	3,769,000	36
1909	28,000	1,120,000	40	1914	92,580	3,685,000	39.8

In 10 years (1904–1913, inclusive) the acreage devoted to rice culture in Arkansas increased from 80 to 104,700 and the production from 5,975 to 3,769,000 bushels. The rather marked decrease in acreage and production in 1914 was due chiefly to abnormally low prices, but statistics for 1915 compiled by the Department of Agriculture indicate a return to normal conditions.

The cereal was grown chiefly on the prairies of the Advance lowland between Crowleys Ridge on the east, the Ozark province on the northwest, and Arkansas River on the southwest. In 1912 the cereal was successfully grown in 13 counties, as follows: Arkansas, Jefferson,

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Lonoke, Prairie, Monroe, Lee, St. Francis, Woodruff, Cross, Poinsett, Craighead, Lawrence, and Clay. Since the data on which this report is based were collected the industry has probably spread to several other counties. The chief productive area is at present within the first four counties named, and the greatest development has been in Grand Prairie, which extends from the northern part of Lonoke County southeastward through Prairie and Arkansas counties, and in Prairie Longue, which extends northwest and southeast through the central part of Lonoke County. Another area in which the industry is rapidly developing extends a little east of north from the vicinity of Brinkley and includes part of Monroe, Lee, St. Francis, Woodruff, Cross, Poinsett, and Craighead counties. The grain also is grown in several scattered localities in the above-mentioned counties.

OUTLOOK.

Though the number of acres of land suitable for rice culture in the area under consideration has not been accurately estimated, only a small part, probably less than 5 per cent, of the available land has been put under cultivation. As water for irrigation is present in great abundance at relatively shallow depths throughout the area, the outlook for the development of the industry to large proportions is most promising. The greater part of the potential rice land is in the Advance lowland west of Crowleys Ridge; immediately east of the ridge, however, there is a belt, nowhere more than 5 or 6 miles wide, extending from the northern boundary southward as far as the southern part of Craighead County, in parts of which the conditions of soil, topography, and available water supply are essentially the same as in the area west of the ridge; near Nettleton, Craighead County, which is in this belt, rice has already been successfully grown.

WATER SUPPLY.

Water for irrigating the rice fields is obtained chiefly from the Pleistocene alluvial deposits which underlie the Advance lowland to depths of 100 to 200 feet. Wells 6 to 12 inches in diameter are sunk to the coarse sands and gravels in the lower part of the deposits, which contain large quantities of water. The wells are equipped with powerful pumps, centrifugal pumps being generally used, and yield from 200 to 4,000 gallons a minute. The cost of drilling and equipping a well ranges from $125 to $5,000; the average cost of sinking the wells and installing the pumping machinery, as estimated from statistics regarding 102 wells, is $1,085 per 1,000 gallons of yield per minute.

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Though wells are the chief source of water for irrigation, lands near streams and bayous might be irrigated with surface water. Surface waters have been utilized only to a small extent in Arkansas, but they are widely used in Louisiana and eastern Texas, where pumping plants on the banks of the streams lift the water to the canals. Utilization of ground water from porous beds near the surface has the added advantage of reducing danger of damage to the land by water-logging and rise of the alkali, both of which troubles have seriously affected much land in other parts of the United States where the ground water level is normally near the surface. The application of water pumped from beneath the irrigated tract tends not only to lower the water table but also to produce downward circulation that removes the alkali. Such circulation is important in growing a crop like rice, for which the duty of water is very low.

SOIL.

The typical soil of the prairies of Arkansas is known as the Crowley silt loam, the name being derived from Crowley, La., where a similar soil is widely developed. Its physical characteristics and availability have been described by Bonsteel[1] as follows:

> The Crowley silt loam is a brown or ashy gray silt loam ranging in depth from 10 to 16 inches, underlain by a gray or mottled heavy silt loam or silty clay which frequently contains concretions of iron and calcium carbonate. The subsoil ranges in color from gray to reddish yellow, mottled with red and brown, and is stiff and impervious in all localities where it has been encountered. * * *
>
> Before the introduction of rice culture upon this soil type very little agricultural use was made of it. In Arkansas the prairie grasses were used for grazing purposes, and the better drained and higher lying portions of the type were beginning to be cultivated to cereal grains and forage crops. These uses of the type, however, are entirely subordinate to its principal utilization as the chief rice-growing soil of the Western Gulf States. While small areas are annually planted to cotton, corn, cowpeas, and even oats or wheat, the great use of the soil is for the production of the rice crop.
>
> The Crowley silt loam, owing to its flat topography, to its slight elevation above the main drainage channels, and to the impervious nature of both the surface soil and subsoil, is in its natural condition for the most part poorly drained. * * *
>
> The Crowley silt loam is the typical rice land of southwestern Louisiana and east-central Arkansas. It is probable that more rice is grown upon this soil than upon all other rice soils in the United States. In fact, the development of this type for agricultural purposes has been almost coextensive with the development of the rice industry in the Western Gulf States.

Although the Crowley silt loam is best adapted to rice culture in the area under consideration, the cultivation of the cereal has been successfully extended to several closely related soils which, as classified by the Bureau of Soils, possess the qualities essential to the

[1] Bonsteel, J. A., U. S. Dept. Agr. Bur. Soils Circ. 54, pp. 3–5, 1912.

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growth of the grain. Knapp,[1] discussing the adaptability of soils to rice culture, states:

> The best soil for rice is a medium loam containing about 50 per cent of clay. This allows the presence of sufficient humus for the highest fertility without decreasing too much the compact nature of the soil. * * *
>
> The best rice lands are underlain by a semi-impervious subsoil. Otherwise the land can not be satisfactorily drained at time of harvest in order to permit the use of improved harvesting machinery. The alluvial lands along the Mississippi in Louisiana are not underlain by hardpan, and they can not be drained sufficiently to permit the use of heavy harvesters and teams of horses.
>
> Gravelly or sandy soils are not adapted to rice cultivation because they do not posses the mechanical conditions for the retention of water, and for other reasons above mentioned. Occasionally, on a light sandy soil, underlain by a stiff subsoil, one or two fairly good crops of rice may be grown, but this is the limit.

DUTY OF WATER.

F. H. King,[2] professor of agricultural physics in the University of Wisconsin, states that the usual duty of water for rice in the United States is 38.6 acres per cubic foot per second, which is equivalent to covering the surface with 6.2 inches of water every 10 days. He also states that in Italy the amount of water applied every 10 days is 5.55 inches, while in Egypt only 3.4 inches is provided for the same period.

Brown[3] estimates that in Egypt 1 cubic meter per second is sufficient for 1,440 acres of rice, his estimate being based on the assumption, corroborated by extensive observations, that rice requires twice as much water as most other crops. This duty is equivalent to 40.75 acres irrigated for each cubic foot per second of water. The water is usually applied after intervals of 9 days. He gives the customary duty in India as 50 acres per cubic foot per second, the water being applied after intervals of 12 days. If the interval is 11 days, this duty becomes 51 acres per cubic foot per second.

Buckley[4] states that a rice crop in the Punjab district of India receives 96 inches of water and requires 48 to 72 inches of water during the growing season; he estimates the duty in Spain as 31 acres per cubic foot per second.

Other estimates of the duty of water in rice culture are 50 to 60 acres per cubic foot per second in Egypt;[5] 40 acres per cubic foot per second in Italy;[6] and 43.75 acres per cubic foot per second in the Cavour Canal district of Italy.[7]

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[1] Knapp, S. A., Rice culture: U. S. Dept. Agr. Farmers' Bull. 417, pp. 8, 9, 1910.

[2] King, F. H., Irrigation and drainage, pp. 231–233, New York, 1908.

[3] Brown, Hanbury, Irrigation, its principles and practices as a branch of engineering, pp. 37, 38, London, 1907.

[4] Buckley, R. B., Facts, figures, and formulæ for irrigation engineers, pp. 126, 133, New York, 1908.

[5] Idem, p. 133.

[6] Estimate by Col. Baird Smith, quoted by Buckley, idem, p. 137.

[7] Estimate by Sir S. C. Moncrieff, quoted by Buckley, idem, p. 136.

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Reports collected by Collier[1] from members of the Arkansas Rice Growers' Association indicate that 57 per cent of the growers commence applying water four or five weeks and 43 per cent two or three weeks after sowing. Sixty per cent keep the water on the field 3 inches or less deep; 28 per cent 3 to 5 inches deep; and 12 per cent 5 or more inches deep. Somewhat more than half the growers reported that they prefer water pumped from wells to surface water, but the rest expressed no preference. More than nine-tenths stated that cold water direct from wells harms the growing plants.

COUNTY DESCRIPTIONS.[2]

ARKANSAS COUNTY.

PHYSIOGRAPHY.

Arkansas County is in the east-central part of the State between Arkansas and White rivers. Its area is 1,000 square miles and its population was reported by the census of 1910 as 16,103. Stock raising and agriculture, which includes trucking, cotton raising, the cutting of prairie hay, the raising of rice, corn, and other cereals, are the principal industries.

The general surface is a slightly undulating plain sloping from an elevation of about 215 feet above sea level in the northern part to 150 feet in the southern part of the county, and comprising the prairies, which include much of the interstream areas, the timbered lands, which include the remainder of the interstream areas, and the flood plains bordering the streams. The prairies are open, grassy tracts forming part of Grand Prairie (p. 27); they cover the northern part of the county and form interstream areas, a few miles to 10 miles wide, extending southward, the southern limit being 5 or 6 miles south of Gillett. In the east the prairies closely border White River, which has cut into the edge of them in places. The general level of the prairies is 45 or 50 feet above the low-water level of Arkansas and White rivers.

The gently undulating interstream timbered lands border the shallow valleys and intertongue irregularly with the prairie lands The flood plains lie a few feet to 30 feet below the level of the prairies and form poorly drained wooded or cultivated tracts 10 to 12 miles in maximum width. The broadest flood plains are in the west, bordering Arkansas River and Bayou Meto, and in the south where the bottom lands of Arkansas and White rivers merge into Mississippi River bottom.

[1] Collier, J. S., Report of investigations concerning rice, Arkansas Rice Growers' Assoc., 1910.

[2] This report was transmitted for publication in June, 1913, and the development of the water resources of northeastern Arkansas as herein indicated is based on data collected prior to that date.

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Arkansas River and its tributary Bayou Meto form the southwestern boundary of the county and White River the eastern boundary. The principal streams within the county are Mill Creek, a tributary of Bayou Meto, and Lagrue River, a tributary of White River.

GEOLOGY.

The surface is underlain by Pleistocene alluvium consisting of clays, sands, and gravels ranging in thickness from 100 to 180 feet or more. The materials are irregularly bedded, but in general grade downward from fine, compact, gray or reddish clays through fine sands to coarse, water-bearing sands and gravels at the base. The coarse basal materials carry water in practically inexhaustible quantities. The surface distribution of the Pleistocene alluvium is coextensive with the distribution of the interstream lands of the county.

The streams have meandered and eroded away the Pleistocene alluvium to undetermined depths, and the valleys thus formed have been partly refilled with Recent alluvium, which constitutes the material of the present flood plains.

The Pleistocene alluvium rests unconformably on a buried surface of undifferentiated Tertiary strata which are believed to consist of sands, clays, and marls and to contain important water-bearing beds, though no logs have been preserved of the few wells that have been drilled deep enough to enter the Tertiary strata. (See well No. 31, p. 157.)

WATER RESOURCES.

GENERAL CONDITIONS.

Domestic supplies.—Water for household use is obtained chiefly from wells 30 to 150 feet deep drawing from the water-bearing sands and gravels of the Pleistocene and Recent alluvial deposits. The waters, as reported by the well owners, differ in quality, some being soft, some hard, some ferruginous, and a few saline, but with rare exceptions they are suitable for domestic and industrial use. No flowing wells have been reported, the static head ranging from 12 to 65 feet below the surface. The Pleistocene and Recent alluvial deposits which extend from the surface to depths of 150 to 180 feet contain large quantities of water suitable for general use, and the water-bearing beds of the Tertiary deposits which underlie the Pleistocene probably contain water in great abundance.

Irrigation.—Water for irrigating the extensive rice lands is obtained chiefly from wells 70 to 232 feet deep. The average depth of such wells—about 136 feet—is greater than that of domestic wells, most of them reaching the coarser sands and gravels forming the

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basal beds of the Pleistocene alluvium. The irrigation wells are equipped to yield by pumping 600 to 2,200 gallons a minute. Detailed information has been recorded concerning 33 wells used in irrigation of rice lands (see table on pp. 154–159), but probably more than 250 wells are in use. The cost of drilling and equipping the wells for pumping, according to reports on 29 wells, ranges from $650 to $3,000, the average cost of drilling and equipping the wells being, in round numbers, $1,500 for each 1,000 gallons a minute of water.

LOCAL SUPPLIES.

Stuttgart.—The municipal waterworks of Stuttgart (population 2,740, census of 1910) is owned by the Stuttgart Water & Electric Light Co., and water is obtained from three wells, two of which are 110 and 131.75 feet deep (Nos. 29 and 30, pp. 156, 157). The water is soft and is forced from the wells by an air compressor having a capacity of 400 gallons a minute; it is stored in a 35,000-gallon reservoir and is distributed through 7 miles of mains. The ordinary direct pressure is 40 pounds per square inch, but it can be increased to 110 pounds per square inch for fire protection. The daily consumption is 180,000 gallons for general use and 700,000 gallons for manufacturing.

The following is a log of the 131.75-foot well drilled in 1909:

Log of well owned by the Stuttgart Water & Electric Light Co., Stuttgart.

	Thickness.	Depth.
Soil and Pleistocene alluvium:	*Feet.*	*Feet.*
Soil and subsoil	12	12
Sand, clay, and gravel	80	92
Gravel, water bearing	39.75	131.75

The material from a depth of 100 feet in a well owned by G. H. Kline, near Stuttgart, consists of very coarse pebbly sand with numerous angular fragments of gray and brown flint, and Gunter Bros., who furnished the sample, state that this is the kind of material from which water is obtained in the vicinity of Stuttgart. The material from a depth of 95 feet in a well owned by Ed Beity, 8 miles northeast of Stuttgart, consists of chunks of drab, yellow, pink, and red clay, in part finely arenaceous, and one sandstone concretion. Gunter Bros., who furnished this sample also, state that similar clay generally lies between the surface and the water-bearing sand and gravel in the region of Stuttgart. Information is meager regarding the oil-prospecting well drilled 2 miles southwest of Stuttgart (No. 31, pp. 156, 157), but the following partial log of it has been prepared from well borings furnished by Mr. E. J. Balle, of Stuttgart.

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Incomplete log of an oil-prospecting well near Stuttgart.

	Thickness.	Depth.
	Feet.	*Feet.*
Not represented by samples	950	950
Fine, dark-gray, micaceous, glauconitic sand	118	1,068
Fine, gray, micaceous, slightly argillaceous sand	10	1,078
Not represented by samples	122	1,200

The materials described are probably of Eocene or Upper Cretaceous age. Mr. G. W. Fagan, of Stuttgart, states that according to the driller, Mr. Schauman, the well was drilled to a depth of 1,200 feet, where hard rock was struck; water-bearing beds were encountered at several levels—one at 800 feet. The waters were cased off without testing their quantity or character.

Irrigation wells.—Wells for irrigating rice lands have been drilled in the vicinity of Stuttgart, Almyra, Dewitt, Gillett, Booty, Arkansas Post, Bayou Meto, Tichnor, St. Charles, Crocketts Bluff, and Humphrey. Logs of the following have been obtained:

Log of well of C. E. Edmund, 6 miles southeast of Stuttgart.

[No. 36, p. 158.]

	Thickness.	Depth.
Soil and Pleistocene alluvium:	*Feet.*	*Feet.*
Soil	3	3
Red clay	47	50
Fine sand	55	105
Coarse sand, water bearing	25	130
Gravel, water bearing	15	145

Log of well of Caspar G. Scheiderer, 1¼ miles southwest of Ulm (Prairie County), in Arkansas County.

[No. 42, p. 158.]

	Thickness.	Depth.
Pleistocene alluvium:	*Feet.*	*Feet.*
Tough red clay	60	60
Quicksand	6	66
Tough chocolate-colored clay	14	80
Sand, water bearing	30	110

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[No. 1, p. 154.]

	Thickness.	Depth.
Soil and Pleistocene alluvium:	*Feet.*	*Feet.*
Soil	3.5	3.5
Red clay	16	19.5
Fine red sand	30	49.5
Red clay	40	89.5
Sand, water bearing	25	114.5
Gravel, water bearing	35.5	150

Log of well of J. M. Satchfield, 4 miles south of Tichnor.

[No. 35, p. 158.]

	Thickness.	Depth.
Pleistocene alluvium:	*Feet.*	*Feet.*
Hard clay	60	60
Sand, water bearing	47	107
Gravel, water bearing	40	147

Log of well of W. N. Carpenter, one-quarter mile west of Booty.

[No. 13, p. 154.]

	Thickness.	Depth.
Pleistocene alluvium:	*Feet.*	*Feet.*
Clay	60	60
Sand	10	70
Gravel, water bearing	93	163

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Wells in Arkansas County.

	Location.				Owner.	Driller.	Authority.	Date completed.	Approximate elevation above sea level.	Depth.	Diameter.	Depth to principal water-bearing bed.	Depth to other water-bearing beds.	Water-bearing formation.
	Place.	T.	R.	Sec.										
									Feet.	*Feet.*	*Inches*	*Feet.*	*Feet.*	
1	Almyra, 2 miles northwest of.	3 S.	4 W.	21, SE. ¼..	H. V. Clutter.....	Layne & Bowler, Stuttgart.	Owner.....	1909	200±	150	12	90–150	.....	Pleistocene alluvium.
2	Almyra, 2½ miles southwest of.	4 S.	4 W.	4, N. ½....	P. and A. L. Westerlund, Orion, Ill.	.....do.....	Wm. Hines...	1908	200±	135	10	96–135	.....	Do.
3	Almyra, 3 miles southeast of.	4 S.	4 W.	1, SW. ¼..	F. E. Hillman....	Owner.....	Owner.....	.....	200±	149	9⅝	110–149	.....	Do.
4	Almyra, 4 miles west of.	3 S.	4 W.	29, W. ½...	J. M. and W. A. Anderson.	.....	W. A. Anderson.	1909	200±	87?	9⅝	50–87?	.....	Do.
5	Almyra, 5 miles southeast of.	4 S.	3 W.	5, NE. ¼...	G. W. Chambers..	Layne & Bowler, Stuttgart.	Owner.....	1909	190±	174	12	95–131	152–174	Do.
6	Almyra, 6 miles southeast of.	4 S.	3 W.	4, NE. ¼...	Austin Rawlings..	Owner.....	.....do.....	1909	(a)	142	10	100–142	65	Do.
7	Almyra, 4 miles east of.	3 S.	3 W.	32, SW. ¼..	W. B. Stroud, Stuttgart.	Layne & Bowler, Stuttgart.	.....do.....	1908	200±	197	9⅝	97	.....	Do.
8	Almyra, 4 miles north of	3 S.	4 W.	3, E. ½.....	S. H. Taggart.....	.....do.....	.....do.....	1908	200±	152	9⅝	90	.....	Do.
9	Arkansas Post (Spanish grant 2307).	8 S.	3 W.	.....	Fritz Quandt.....	E. Nichols, Gillett.	.....do.....	1907	.....	85	2	80–85	.....	Quaternary alluvium.
10	Arkansas Post, 4 miles north of.	7 S.	3 W.	21, SW. ¼..	J. A. Nutter, Gillett.	E. C. Nutter, Gillett.	Driller.....	1911	(b)	130	8½	95–130	35, 55	Pleistocene alluvium.
11	Bayou Meto, 1½ miles southeast of.	5 S.	5 W.	36, N. ½ SE. ¼.	John Rodgers.....	L. B. Stephens, De Witt.	Owner.....	1909	.....	100	10	80–100	60	Do.
12	Booty, 2½ miles west of.	7 S.	3 W.	36, NE. ¼..	P. Whiting, Arkansas Post; and C. L. Morgan, De Witt.	William Cromwell, Stuttgart.	C. L. & S. A. Morgan.	1910	.....	137	12	.....	.....	Do.
13	Booty, one-fourth mile west of.	8 S.	2 W.	5, SE. ¼...	W. N. Carpenter, De Witt.	Owner.....	Owner.....	1910	.....	163	12	70–163	.....	Do.
14	Crocketts Bluff, 3 miles south of.	3 S.	2 W.	34, NW. ¼..	A. M. Adams, Rockville, Ind.	A. F. Selig, Stuttgart.	.....do.....	1911	190±	144	9⅝	.....	.....	Do.

a Elevation about 50 feet above low-water level of La Grue River.

b Elevation about 25 feet above low-water level of Arkansas River.

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	Location.				Character of principal water-bearing bed.	Level of water below surface.	Yield per minute.	Method of lift.	Cost of well.	Cost of machinery.	Use.	Quality of water.	Remarks.
	Place.	T.	R.	Sec.									
						Feet.	*Galls.*						
1	Almyra, 2 miles northwest of.	3 S.	4 W.	21, SE. ¼...	Sand and gravel...	50	1,600	.....	$2,000	$800	Irrigation.....	.....	100 feet of 24-inch casing; 50 feet of 12-inch casing. Analysis 1, p. 302.
2	Almyra, 2½ miles southwest of.	4 S.	4 W.	4, N. ½.....	.....do.....	48	1,035	Steam	2,000		.....do.....	.....	Diameter of well at mouth, 24 inches.
3	Almyra, 3 miles southeast of.	4 S.	4 W.	1, SW. ¼...	Coarse gravel.....	47	900	...do..	600	400	.....do.....	Hard.....	
4	Almyra, 4 miles west of.	3 S.	4 W.	29, W. ½...	Sand and gravel...	55	1,100	Gas...	2,000	700	.....do.....	Soft.....	87 feet of 24-inch casing; 50 feet of 9⅝-inch casing.
5	Almyra, 5 miles southeast of.	4 S.	3 W.	5, NE. ¼...	.....do.....	52	1,300	...do..	2,600		.....do.....	.....	From top down, 95 feet of casing, 32 feet of screen, 28 feet of casing and 19½ feet of screen. Analysis 2, p. 302.
6	Almyra, 6 miles southeast of.	4 S.	3 W.	4, NE. ¼...	Coarse sand and gravel.	50	600+	...do..	500	200	.....do.....	Soft.....	Diameter of well at top, 4½ feet.
7	Almyra, 4 miles east of.	3 S.	3 W.	32, SW. ¼..	Sand and gravel...	53	1,700	.....	1,800	600	Domestic and irrigation.	Medium soft..	Diameter at top 24 inches and at bottom 9⅝ inches.
8	Almyra, 4 miles north of.	3 S.	4 W.	3, E. ½.....	Sand.....	50	650	Steam	1,200	525	...do.....	Hard and ferruginous.	24-inch pit to depth of 65 feet; 35 feet of 9⅝-inch casing and 52 feet of 9⅝-inch screen.
9	Arkansas Post (Spanish grant 2307).	8 S.	3 W.	.....	.....do.....	25	.....	Hand.	50	.....	Domestic.....	Hard.....	
10	Arkansas Post, 4 miles north of.	7 S.	3 W.	21, SW. ¼..	Coarse sand and gravel.	26	700	Steam	800	600	Irrigation.....	.....do.....	
11	Bayou Meto, 1½ miles southeast of.	5 S.	5 W.	36, N. ½ SE. ¼.	Sand and gravel...	31	600	...do..	500	350	.....do.....	.....	Pit 6 feet square to depth of 30 feet, and 70 feet of 10-inch casing to bottom of well. Analysis 3, p. 302.
12	Booty, 2½ miles west of.	7 S.	3 W.	36, NE. ¼..	.....do.....	28±	1,800	...do..	1,900		.....do.....	.....	32-inch steel pit to depth of 60 feet, 37 feet of 12-inch casing to depth of 97 feet, and 40 feet of 12-inch strainer to bottom of well. Analysis 4, p. 302.
13	Booty, one-fourth mile west of.	8 S.	2 W.	5, SE. ¼....	.....do.....	30	1,500+	...do..	1,250?	350	.....do.....	Hard.....	
14	Crockett's Bluff, 3 miles south of.	3 S.	2 W.	34, NW. ¼.	.....	45	.....	Gas...	1,600	1,750	.....do.....	Soft.....	28-inch pit to depth of 70 feet and 9⅝-inch casing to bottom of well.

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Wells in Arkansas County—Continued.

	Location. Place	T.	R.	Sec.	Owner	Driller.	Authority	Date of [illegible]	[illegible]	Depth	[illegible]	[illegible]	[illegible]	Water-bearing formation
									Feet	Feet	Inches	Feet	Feet	
15	De Witt, 6 miles north east of.				F. M. Mitchell	Elmer Smith, Stuttgart	R. M. Dickey	1909	(a)	140	10	60-140		Pleistocene alluvium
16	De Witt, one-fourth mile southeast of.	5 S.	3 W.	10, SE. ¼	W. N. Carpenter	Owner	Owner	1910	180±	180	10	90-180		Do.
17	De Witt, 6½ miles east of	4 S.	2 W.	20, SW. ¼	George Lacotte	Elmer Smith, Stuttgart	do	1909	180±	145				Do.
18	Gillett, 3½ miles south of				S. V. Wise	A. F. Selig, Stuttgart	do	1910	180±	105	14	45-105		Do.
19	do				Ulrich Bauer	do	do	1911	180±	142	10	100-142		Do.
20	Gillett, 3½ miles north east of.	6 S.	3 W.	24, SW. ¼	William Sager		Andrew Sager	1910	(b)	145	9⅝	45-145		Do.
21	Humphrey, 1¾ miles southeast of.	8 S.	6 W.	30, SE. ¼	Lewis Sachs, Jonesboro		H. Sachs	1910	190±	115	10			Quaternary alluvium
22	Humphrey, 600 feet west of post office.				J. K. Anthony	Owner	Owner	1910	191±	64	8	30-64		Do.
23	Nady, 1 mile west of	8 S.	2 W.	8	M. M. Mitchell	J. M. Satchfield, Tichnor.	do	1909		58	8	58		Do.
24	Nady, 1½ miles east of (Spanish grant No. 2125).				N. B. Menard	Owner	do	1907		56	18	40-56		Do.
25	Nady, 2½ miles south of (Spanish grant No. 2303).				do	do	do	1906		47	18	37-47		Do.
26	Nady, 1½ miles south of (Spanish grant No. 2303).	8 S.	2 W.		J. Menard	J. M. Satchfield, Tichnor.	do		(c)	48	8	47		Do.
27	St. Charles, 3½ miles northwest of.				W. H. Norsworthy & Co.	United Well Works, Stuttgart.	do	1911		180	18			Pleistocene alluvium.
28	St. Charles, 5 miles southwest of.	4 S.	2 W.	26, NE. ¼	W. H. Norsworthy and W. Hargrave.	Layne & Bowler, Stuttgart.	W. Hargrave	1910		282	9⅝			Do.
29	Stuttgart				Stuttgart Water & Electric Light Co.	Charles Williamson.	Sam Harper	1909	213±	110	8	110		Do.
30	do				do	J. W. Beckler	do	1909	213±	131.75	10	131	110, 120	Do.

[a] Elevation about 60 feet above low-water level of White River.
[b] Elevation about 50 feet above low-water level of La Grue River.
[c] Elevation about 40 feet above low-water level of Arkansas River.

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	Location.				Character of principal water-bearing bed.	Level of water below surface.	Yield per minute.	Method of lift.	Cost of well.	Cost of machinery.	Use.	Quality of water.	Remarks.
	Place.	T.	R.	Sec.									
						Feet.	*Galls.*						
15	De Witt, 6 miles northeast of.	.....	.....	.....	Gravel and rock...	50	2,200	Steam	$2,230		Irrigation.....	Hard.....	Diameter at top, 24 inches.
16	De Witt, one-fourth mile southeast of.	5 S.	3 W.	10, SE. ¼...	Gravel.....	50	.....	.....	.....		.....	.....	Intended for irrigation of rice fields, but on account of improper construction will be rebuilt.
17	De Witt, 6½ miles east of.	4 S.	2 W.	29, SW. ¼.	Clay and gravel...	.....	1,800	Steam	2,300		Irrigation.....	.....	Pit for pump to depth of 60 feet. Analysis 5, p. 302.
18	Gillett, 3½ miles south of.	.....	.....	.....	Sand and gravel...	26	.....	...do..	.....		.....do.....	.....	Irrigates 160 acres of rice land.
19	.....do.....	.....	.....	.....	.....do.....	32	1,200	.....	1,500		.....do	Hard.....	
20	Gillett, 3½ miles northeast of.	6 S.	3 W.	24, SW. ¼.	Gravel.....	38	1,500	Steam	2,000		.....do	Ferruginous...	
21	Humphrey, 1½ miles southeast of.	3 S.	6 W.	30, SE. ¼..	Sand and gravel...	18	1,000	.....	$500	$150	.....do.....	Hard.....	
22	Humphrey, 600 feet west of post office.	.....	.....	.....	Coarse sand and gravel.	8	800	.....	43	125	.....do.....	.....do.....	
23	Nady, 1 mile west of.	8 S.	2 W.	8.....	Sand.....	30	.....	.....	25	.....	Domestic.....	.....do.....	
24	Nady, 1½ miles east of (Spanish grant No. 2425).	.....	.....	.....	Gray sand.....	40	.....	Hand.	.....	.....	.....do.....	Ferruginous...	
25	Nady, 2½ miles south of (Spanish grant No. 2303).	.....	.....	.....	Sand.....	12	.....	...do...	.....	.....	.....do.....	.....	
26	Nady, 1½ miles south of (Spanish grant No. 2303).	8 S.	2 W.	.....	.....do.....	12	.....	...do...	.....	.....	.....do.....	.....	
27	St. Charles, 3½ miles northwest of.	.....	.....	.....	Gravel.....	65	1,500	Steam.	1,850		Irrigation.....	.....	Analysis 6, p. 302.
28	St. Charles, 5 miles southwest of.	4 S.	2 W.	26, NE. ¼..	Sand and gravel...	50	1,200	...do...	3,000		.....do.....	Alkaline.....	9½-inch screen in lower 96 feet of well.
29	Stuttgart.....	.....	.....	.....	Gravel.....	.....	75	Air....	.....	.....	Municipal supply.	Soft.....	These two wells and another similar well (depth not reported) furnish the municipal water supply.
30	.....do.....	.....	.....	.....	.....do.....	47	250	...do...	.....	.....	.....do.....	.....do.....	

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Wells in Arkansas County—Continued.

	Location.				Owner.	Driller.	Authority.	Date completed.	Approximate elevation above sea level.	Depth.	Diameter.	Depth to principal water-bearing bed.	Depth to other water-bearing beds.	Water-bearing formation.
	Place.	T.	R.	Sec.										
									Feet.	*Feet.*	*Inches*	*Feet.*	*Feet.*	
31	Stuttgart, 2 miles southwest of.	3 S.	5 W.	5.....	Stuttgart Oil & Gas Co.	Mr. Schauman....	G. W. Fagan..	1907	210±	1,200	3	.....	.....	
32	Stuttgart, 3 miles south of.	3 S.	5 W.	4, NE. ¼...	J. P. Rich.....	Layne & Bowler, Stuttgart.	Owner.....	1909	210±	165	24	90	.....	Pleistocene alluvium.
33	Stuttgart, 2 miles southwest of.	3 S.	5 W.	5, NW. ¼..	E. G. Reinsch.....	.....do.....	.....do.....	1909	210±	135	9⅝	100	.....	Do.
34	Stuttgart, 1½ miles west of.	2 S.	5 W.	30.....	G. W. Fagan.....	.....do.....	.....do.....	1908	210±	120	9⅝	70	.....	Do.
35	Stuttgart, 4 miles north of.	2 S.	5 W.	4.....	Pettit & Pettit....	.....do.....	Edwin Pettit.	1910	215±	144.5	10	50	.....	Do.
36	Stuttgart, 6 miles southeast of.	3 S.	4 W.	5.....	C. E. Edmund....	.....do.....	Owner.....	1910	200±	145	12	.....	.....	Do.
37	Stuttgart, 7½ miles east of.	2 S.	4 W.	22, NE. ¼..	Mrs. A. F. Duensing.	.....do.....	H. E. Duensing.	1909	200±	123	9⅝	.....	.....	Do.
38	Stuttgart, about 12 miles southeast of.	.....	.....	.....	J. M. Ellis.....	.....do.....	Owner.....	1910	200±	150?	10	110	.....	Do.
39	Tichnor, 4 miles south of	7 S.	2 W.	16, SW. ¼..	J. M. Satchfield...	William Cromwell, Stuttgart.	.....do.....	1910	(a)	147	9⅝	100-147	.....	Do.
40	Tichnor, 2½ miles southeast of.	7 S.	2 W.	4, SE. ¼...	August Paulman..	Henry Luckett, Stuttgart.	.....do.....	1910	.....	162	10	56-162	.....	Do.
41	Tichnor, 1½ miles southeast of.	.....	.....	.....	Botts and Eckles..	Beckler Well Co., Stuttgart.	G. W. Botts...	.....	.....	70	12	.....	.....	Do.
42	Ulm, 1¼ miles southwest of.	2 S.	4 W.	6, NE. ¼...	C. G. Scheiderer, Stuttgart.	W. H. Wheeler, Devall Bluff.	Owner.....	1910	209±	110	8	80-110	.....	Do.

a Elevation about 30 feet above low-water level of Arkansas River.

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	Location.				Character of principal water-bearing bed.	Level of water below surface.	Yield per minute.	Method of lift.	Cost of well.	Cost of machinery.	Use.	Quality of water.	Remarks.
	Place.	T.	R.	Sec.									
						Feet.	*Galls.*						
31	Stuttgart, 2 miles southwest of.	3 S.	5 W.	5.....	.....	.....	.....	.....	.....	.....	.....	.....	Drilled as an oil-prospecting well; diameter at top, 10 inches, at bottom, 3 inches; water-bearing beds at several levels, one at a depth of 800 feet.
32	Stuttgart, 3 miles south of.	3 S.	5 W.	4, NE. ¼...	Gray sand.....	.....	1,550	Steam.	$2,100		Irrigation.....	Soft.....	
33	Stuttgart, 2 miles southwest of.	3 S.	5 W.	5, NW. ¼..	Sand and gravel...	35	1,200	...do...	.....	.....	.....do.....	.....do.....	
34	Stuttgart, 1½ miles west of.	2 S.	5 W.	30.....	Clear gravel.....	30	1,500	...do ..	1,500	500	Domestic and irrigation.	Medium hard.	24-inch pit to depth of about 70 feet; 9⅝-inch casing and screen extend to bottom of well; length of screen about 40 feet.
35	Stuttgart, 4 miles north of.	2 S.	5 W.	4.....	Gravel.....	40	1,000	...do...	.....	.....	.....do.....	.....	
36	Stuttgart, 6 miles southeast of	3 S.	4 W.	5.....	Sand and gravel...	45	1,000	Gas...	1,600	600	.....do.....	Soft.....	24-inch pit to depth of 103 feet; 42 feet of 12-inch casing and screen to bottom of well.
37	Stuttgart, 7½ miles east of.	2 S.	4 W.	22, NE. ¼..	Coarse gravel.....	40	1,500	Steam.	2,250		Irrigation.....	.....	24-inch pit.
38	Stuttgart, about 12 miles southeast of.	.....	.....	.....	Gravel.....	45?	1,200	...do...	2,500		Domestic, irrigation, manufacture of ice, and bottling.	Soft.....	
39	Tichnor, 4 miles south of.	7 S.	2 W.	16, SW. ¼..	.....do.....	34	2,000	...do...	2,000		Irrigation.....	Salty, ferruginous, and very hard.	11¼-inch strainer in lower 40 feet of well.
40	Tichnor, 2½ miles southeast of.	7 S.	2 W.	4, SE. ¼...	.....do.....	30	1,800	...do...	1,900	760	.....do.....	.....	13-inch screen from depth of 85 to 155 feet. Analysis 7, p. 302.
41	Tichnor, 1½ miles southeast of.	.....	.....	.....	Sand and gravel...	33	1,000	.....	1,500	600	.....do.....	Hard and salty	
42	Ulm, 1½ miles southwest of.	2 S.	4 W.	6, NE. ¼...	Sand.....	54	210	Steam.	650		.....do.....	.....	Analysis 8, p. 302.

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Wells in Arkansas County—Continued.

	Location.				Owner.	Driller.	Authority.	Date completed.	Approximate elevation above sea level.	Depth.	Diameter.	Depth to principal water-bearing bed.	Depth to other water-bearing beds.	Water-bearing formation.
	Place.	T.	R.	Sec.										
									Feet.	*Feet.*	*Inches*	*Feet.*	*Feet.*	
31	Stuttgart, 2 miles southwest of.	3 S.	5 W.	5.....	Stuttgart Oil & Gas Co.	Mr. Schauman....	G. W. Fagan..	1907	210±	1,200	3	.....	.....	
32	Stuttgart, 3 miles south of.	3 S.	5 W.	4, NE. ¼...	J. P. Rich.....	Layne & Bowler, Stuttgart.	Owner.....	1909	210±	165	24	90	.....	Pleistocene alluvium.
33	Stuttgart, 2 miles southwest of.	3 S.	5 W.	5, NW. ¼..	E. G. Reinsch.....	.....do.....	.....do.....	1909	210±	135	9⅝	100	.....	Do.
34	Stuttgart, 1½ miles west of.	2 S.	5 W.	30.....	G. W. Fagan.....	.....do.....	.....do.....	1908	210±	120	9⅝	70	.....	Do.
35	Stuttgart, 4 miles north of.	2 S.	5 W.	4.....	Pettit & Pettit....	.....do.....	Edwin Pettit.	1910	215±	144.5	10	50	.....	Do.
36	Stuttgart, 6 miles southeast of.	3 S.	4 W.	5.....	C. E. Edmund....	.....do.....	Owner.....	1910	200±	145	12	.....	.....	Do.
37	Stuttgart, 7½ miles east of.	2 S.	4 W.	22, NE. ¼..	Mrs. A. F. Duensing.	.....do.....	H. E. Duensing.	1909	200±	123	9⅝	.....	.....	Do.
38	Stuttgart, about 12 miles southeast of.	.....	.....	.....	J. M. Ellis.....	.....do.....	Owner.....	1910	200±	150?	10	110	.....	Do.
39	Tichnor, 4 miles south of	7 S.	2 W.	16, SW. ¼..	J. M. Satchfield...	William Cromwell, Stuttgart.	.....do.....	1910	(a)	147	9⅝	100–147	.....	Do.
40	Tichnor, 2½ miles southeast of.	7 S.	2 W.	4, SE. ¼...	August Paulman..	Henry Luckett, Stuttgart.	.....do.....	1910	.....	162	10	56–162	.....	Do.
41	Tichnor, 1½ miles southeast of.	.....	.....	.....	Botts and Eckles..	Beckler Well Co., Stuttgart.	G. W. Botts...	.....	.....	70	12	.....	.....	Do.
42	Ulm, 1¼ miles southwest of.	2 S.	4 W.	6, NE. ¼...	C. G. Scheiderer, Stuttgart.	W. H. Wheeler, Devall Bluff.	Owner.....	1910	209±	110	8	80–110	.....	Do.

a Elevation about 30 feet above low-water level of Arkansas River.

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	Location.				Character of principal water-bearing bed.	Level of water below surface.	Yield per minute.	Method of lift.	Cost of well.	Cost of machinery.	Use.	Quality of water.	Remarks.
	Place.	T.	R.	Sec.									
						Feet.	*Galls.*						
31	Stuttgart, 2 miles southwest of.	3 S.	5 W.	5.....	.....	.....	.....	.....	.....	.....	.....	.....	Drilled as an oil-prospecting well; diameter at top, 10 inches, at bottom, 3 inches; water-bearing beds at several levels, one at a depth of 800 feet.
32	Stuttgart, 3 miles south of.	3 S.	5 W.	4, NE. ¼...	Gray sand.....	.....	1,550	Steam.	$2,100		Irrigation.....	Soft.....	
33	Stuttgart, 2 miles southwest of.	3 S.	5 W.	5, NW. ¼..	Sand and gravel...	35	1,200	...do...	.....	.....	.....do.....	.....do.....	
34	Stuttgart, 1½ miles west of.	2 S.	5 W.	30.....	Clear gravel.....	30	1,500	...do..	1,500	500	Domestic and irrigation.	Medium hard.	24-inch pit to depth of about 70 feet; 9⅝-inch casing and screen extend to bottom of well; length of screen about 40 feet.
35	Stuttgart, 4 miles north of.	2 S.	5 W.	4.....	Gravel.....	40	1,000	...do...	.....	.....	.....do.....	.....	
36	Stuttgart, 6 miles southeast of	3 S.	4 W.	5.....	Sand and gravel...	45	1,000	Gas...	1,600	600	.....do.....	Soft.....	24-inch pit to depth of 103 feet; 42 feet of 12-inch casing and screen to bottom of well.
37	Stuttgart, 7½ miles east of.	2 S.	4 W.	22, NE. ¼..	Coarse gravel.....	40	1,500	Steam.	2,250		Irrigation.....	.....	24-inch pit.
38	Stuttgart, about 12 miles southeast of.	.....	.....	.....	Gravel.....	45?	1,200	...do...	2,500		Domestic, irrigation, manufacture of ice, and bottling.	Soft.....	
39	Tichnor, 4 miles south of.	7 S.	2 W.	16, SW. ¼..	.....do.....	34	2,000	...do...	2,000		Irrigation.....	Salty, ferruginous, and very hard.	11¼-inch strainer in lower 40 feet of well.
40	Tichnor, 2½ miles southeast of.	7 S.	2 W.	4, SE. ¼...	.....do.....	30	1,800	...do...	1,900	760	.....do.....	.....	13-inch screen from depth of 85 to 155 feet. Analysis 7, p. 302.
41	Tichnor, 1½ miles southeast of.	.....	.....	.....	Sand and gravel...	33	1,000	.....	1,500	600	.....do.....	Hard and salty	
42	Ulm, 1½ miles southwest of.	2 S.	4 W.	6, NE. ¼...	Sand.....	54	210	Steam.	650		.....do.....	.....	Analysis 8, p. 302.

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CLAY COUNTY.

PHYSIOGRAPHY.

Clay County, in the extreme northeastern part of the State, comprises an area of 654 square miles. The census of 1910 reported its population as 23,690. Agriculture, including trucking, the raising of cotton and of cereals, and horticulture, including the growing of the common fruits, are the principal industries.

Except for a few square miles of the Ozark province included in its extreme northwestern section, the county comprises parts of the three topographic divisions—Crowleys Ridge, the Advance lowland, and the Mississippi lowland—into which the Mississippi embayment of the Gulf Coastal Plain is separable.

Crowleys Ridge is a broken, hilly area, 5 to 10 miles wide, extending from the northeastern corner of the county southwestward to and beyond the county line. Its maximum elevation is about 550 feet above sea level, or 250 feet above the level of the Advance lowland to the west. The highest part of the ridge lies somewhat west of the center, the drainage being chiefly to the east into St. Francis River; along the divide and west of the divide the surface is characterized by narrow ridges and steep slopes, many of which are wooded; west of the divide the drainage is into Cache River. To the east the hills are lower, their tops are broader, and their slopes more rounded, so that more extensive cultivation is possible here than in the more rugged area to the west.

The Advance lowland, which includes practically all the county west of Crowleys Ridge, is a nearly level plain 275 to 300 feet above sea level. Current River, in the northwest, which flows southward, Black River, which flows southwestward through the central part of the lowland, and Cache River which flows southwestward near the foot of Crowleys Ridge, traverse shallow, swampy, and wooded valleys several miles in width, lying only a few feet below the level of the plain. The interstream areas are characterized by low, parallel sand ridges and ancient abandoned stream channels.

That part of the county lying east of Crowleys Ridge is included in the Mississippi lowland and lies 275 to 300 feet above sea level. St. Francis River, which forms the eastern boundary, flows through a broad, shallow, partly wooded, and swampy valley known as the "sunk lands," lying only a few feet below the general level of the Mississippi lowland. The lowland plain slopes gradually upward from the river to the foot of Crowleys Ridge, a strip several miles ide just east of and bordering the ridge being a few feet higher d therefore better drained than the lowland to the east.

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GEOLOGY.

Paleozoic rocks of pre-Carboniferous age outcrop in an area a few miles square in the extreme northwestern section and lie buried beneath deposits of the Coastal Plain throughout the remainder of the county; their upper eroded surface inclines eastward, probably reaching a maximum depth of 1,000 feet or more in the extreme east.

Sands and clays of Eocene age belonging to the Wilcox formation form the body of Crowleys Ridge and outcrop in places on the sides and slopes of the hills. The sands are locally indurated to sandstones and quartzites; fossil leaves of Wilcox age have been found in a soft sandstone 3 or 4 miles southwest of Boydsville. (See p. 58.) The beds are lignitic in places, and southwest of Boydsville lignite is exposed near the base of the west slope of the ridge. In a well dug near the same place lignitic beds were encountered to a depth of 40 feet below the level of the plain to the west. It is reasonably certain that strata of Eocene age underlie the remainder of the county beneath the Pleistocene and Recent alluvium, and that at an unknown depth the Eocene is underlain by strata of Cretaceous age. The deposits of the Coastal Plain rest on a basement of Paleozoic rocks.

The Eocene strata in Crowleys Ridge are unconformably overlain by a few feet to 30 feet or more of sands and gravels of late Pliocene (?) age belonging to the Lafayette formation. The gravels consist chiefly of partly rounded chert pebbles and cobbles, with subordinate amounts of smoothly rounded quartz pebbles, locally cemented by iron oxide to form hard conglomerates.

The light yellow or brown to dark-red noncalcareous loess and loesslike clay of Pleistocene age that overlie the gravels and cap the ridge have in places been eroded entirely away from above the gravels. Both the loess and the gravels have been in part reworked and redeposited on the sides of the hills or have found their way down the slopes by creep.

The Advance lowland west of Crowleys Ridge is underlain to a depth of 150 or 200 feet by alluvial sands, clays, and gravels, chiefly of Pleistocene age but in part of Recent age. In general the coarser sands and gravels occur toward the basal portion and carry large quantities of water. The alluvium is believed to rest on a buried eroded surface of Tertiary strata.

The Mississippi lowland east of Crowleys Ridge is underlain to a depth of 150 feet or more by alluvial sands, clays, and gravels, probably for the most part of Recent age, but perhaps in part of Pleistocene age, which also carry large quantities of water.

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WATER RESOURCES.

GENERAL CONDITIONS.

An abundant supply of water for domestic and industrial use is obtained throughout the county from wells ranging in depth from 10 to 200 feet. In the lowlands the water is derived principally from the sands and gravels of the Pleistocene and Recent alluvium; in Crowleys Ridge the wells tap the water-bearing sands of the underlying Tertiary deposits. According to the reports of well owners, the quality of the well waters varies considerably from place to place, some being hard, some soft, and some ferruginous.

Small springs are numerous in Crowleys Ridge, and some of them are utilized for domestic supplies. They emerge from the gravel beds of the Lafayette formation or from the underlying Tertiary sands, and many of them yield waters made turbid or milky by fine suspended particles of clay.

In the eastern half of the county artesian water could probably be obtained from the deeply buried Tertiary and Cretaceous deposits at an estimated maximum depth of 1,000 feet. Wells sunk in the Mississippi lowlands east of Crowleys Ridge will probably yield flowing water.

LOCAL SUPPLIES.

Source.—None of the towns and villages of the county has a water-supply system, although three of them, according to the census of 1910, have populations exceeding 1,000, as follows: Rector, 1,859; Corning, 1,439; and Piggott, 1,150. Water for domestic and industrial use is obtained chiefly from wells. (See table on p. 164.)

The strata penetrated by several wells are indicated as follows:

Logs of several wells furnishing local water supply.

St. Louis, Iron Mountain & Southern Ry. Co., Knobel.

[Authority, C. H. Winters, driller, Harrisburg, Ark.]

	Thickness.	Depth.
Soil and Pleistocene alluvium:	*Feet.*	*Feet.*
Clay	8	8
Sand and clay	12	20
Fine yellow sand, water bearing	12	32
Coarse sand and gravel, water bearing (see analysis No. 9 on p. 302)	18	50
Caraway & Freidenburg, Piggott (No. 6, p. 164).		
Soil and Pleistocene alluvium:		
Alluvial soil	30	30
Blue clay; well stopped on water-bearing gravel	44	74
Patter & Co., Piggott (No. 7, p. 164).		
Pleistocene alluvium:		
Irregularly bedded sands and clays	30	30
Tough blue material with a mixture of shells and fossil wood, becoming a pinkish color toward base; water bearing	65	95
Gravel, water bearing	3.5	98.5

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Well at Campbell, Mo.—The following record of a well at Campbell, Dunklin County, Mo., quoted from a report by Shepard,[1] is of interest in connection with the deep-seated waters of Clay County:

At Campbell, Dunklin County, a well is located on the land of the Campbell Lumber Co. Depth, 960 feet; elevation above tide, about 310 feet; casing, 4-inch, to 910 feet; temperature of water, 72° F.; flow, 16 gallons per minute; date of completion, September, 1902; drillers, Johnson & Fleming, Memphis, Tenn.; cost, $3,000. The principal source of water was found at 490 feet in sand, and another water-bearing horizon was found at 145 feet. The water is somewhat soft, though rather saline, and contains sulphureted hydrogen. The following log of this well was furnished by Mr. William B. Johnson, of Memphis, Tenn.:

Log of well of Campbell Lumber Co., Campbell, Dunklin County, Mo.

	Thickness.	Depth.
	Feet.	*Feet.*
Loess? (112 feet):		
Yellow clay, a little darker than that on Crowleys Ridge	112	112
Lafayette (43 feet):		
Orange sand and gravel; the sand has many white loamy clay nodules mixed in it	43	155
Lagrange formation (785 feet):		
Very hard black and brown clay or marl, with numerous very hard strata from 1 to 23 inches thick, composed largely of iron pyrites. At some point between 700 and 750 feet a bed of logs 10 or 12 feet thick was penetrated. This clay differed from any other bed struck in the bottoms in containing no sand strata, and not even a trace of the "gray sand" found in other wells was noted	785	940
Ripley sands (20 feet):		
Very fine black sand, with a large percentage of mica in small grains. Water headed about 7 feet above surface and flowed 16 gallons per minute; had brackish taste	20	960

The water from this well is used for boiler and drinking purposes. It is probable that the bottom of the well is not far from bedrock.

The yellow clay correlated by the author questionably with the loess, and the sand and gravel correlated with the Lafayette, are probably Pleistocene alluvial deposits. The correlations indicated for the remainder of the section are not based on paleontologic evidence and can scarcely be considered conclusive. The section is important chiefly as showing the great thickness of clay at this place (785 feet) and the presence of a water-bearing sand beneath the clay.

Well water for irrigation.—A well 5 miles east of Knobel (No. 3, p. 164) is used for irrigating 52 acres of rice land. This well penetrated the material shown by the following log:

Log of well of the Knobel Rice Co., 5 miles east of Knobel.

	Thickness.	Depth.
	Feet.	*Feet.*
Pleistocene alluvium:		
Clay, commonly called hardpan	28	28
Sand becoming coarser toward base; water bearing throughout	150	178

[1] Shepard, Edward M., Underground waters of Missouri: U. S. Geol. Survey Water-Supply Paper 195, pp. 174, 175, 1907.

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No.	Location	Depth	Diameter	Remarks	Driller	Authority	Date completed	Depth to water	Depth to rock	Yield	Remarks
1	Greenway	301 N.	8 in.	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
2	Kimball	301 N.	8 in.	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
3	Kimball, 3 miles east of	10 N.	6 in.	III, N W. 4	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
4	Bigwell	301 N.	8 in.	III	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
5	do	301 N.	8 in.	III	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
6	do	301 N.	8 in.	III, N W. 4	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
7	Pollard, one fourth mile west of	301 N.	8 in.	III, N E. 4	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
8	Pollard, ½ mile north west of	301 N.	7 in.	14, N E. 4	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
9	Pollard, ½ mile north west of	301 N.	7 in.	300	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
10	Pollard, ¾ mile north west of	301 N.	7 in.	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
11	Pollard, ¾ mile north west of	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
12	Hewitt, one-half mile west of	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
13	Hewitt	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

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	Location.				Character of principal water-bearing bed.	Level of water below surface.	Yield per minute.	Method of lift.	Cost of well.	Cost of machinery.	Use.	Quality of water.	Remarks.
	Place.	T.	R.	Sec.									
						Feet.	*Galls.*						
1	Greenway	20 N.	8 E.	28		20	5	Hand			Domestic	Ferruginous(?)	
2	Knobel						23+				Boilers		This and another similar well together yield 2,000,000 gallons monthly. Analysis 9, p. 302.
3	Knobel, 5 miles east of.	19 N.	5 E.	10, NW. ¼	Sand	14	2,000	Steam.	$1,500	$750	Irrigation	Soft	Irrigates 52 acres.
4	Piggott	20 N.	8 E.	11	Gravel	35		Hand.	35	18	Domestic	Hard	Bored type, tile cribbing.
5	.....do	20 N.	8 E.	11			10	...do			Drinking	Soft, slightly ferruginous.	
6	.....do	20 N.	8 E.	11, SW. ¼	Gravel	20		...do	25	18	.....do	Ferruginous	Bored type; wood cribbing extends to 74 feet.
7	.....do	20 N.	8 E.	10, SE. ¼	Sand and gravel	12	10		70		Domestic	Hard	Bored type; tile cribbing.
8	Pollard, one-fourth mile west of.				.....do	63					.....do		Bored type.
9	Pollard, 3 miles northwest of.	21 N.	7 E.	14, NE. ¼ SE. ¼.	White sand	16		Hand.			.....do	Ferruginous	Driven type. Four similar wells, depths 49, 51, 51, and 53 feet.
10	Pollard	21 N.	7 E.	22	.....do			...do	20	18	Domestic and boiler.	Soft	
11	Pollard, 3 miles northwest of.				.....do			Flows.	35		.....do	.....do	80 feet of 1½-inch casing; water will rise to or slightly above surface; it is cut off by an elbow 10 feet below surface and flows into a pit.
12	Rector, one-half mile west of.				Sand	48	9	Gas			Domestic	.....do	Bored type.
13	Rector										Drinking, boilers.		Yields abundant supply.

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CRAIGHEAD COUNTY.

PHYSIOGRAPHY.

Craighead County comprises an area of 687 square miles. At the time of the census of 1910 its population was 27,627. Lumbering and agriculture, including the raising of cotton, cereals, vegetables, and hay are the chief industries. Fruits, such as peaches, apples, and pears are also grown. Jonesboro, the county seat, is a shipping point for hardwood timber.

The county includes parts of the three main topographic divisions—Crowleys Ridge, the Advance lowland, and the Mississippi lowland—into which the Mississippi embayment is divisible.

Crowleys Ridge, a belt of hilly, partly wooded country, extends north and south through the county a little west of the center, rising to a maximum elevation of 475 or 500 feet above sea level, or 200 to 250 feet above the level of the lowlands to the east and west. From the northern boundary southward the ridge is 10 to 12 miles wide to a point 3 or 4 miles south of Jonesboro, where it narrows abruptly to a width ranging from one-half mile to 4 miles. A deep gap in the ridge in the vicinity of Dee is traversed by the Helena branch of the St. Louis, Iron Mountain & Southern Railway. The ridge has been strongly dissected, chiefly by the headwater streams of Bayou De Vue, a tributary of Cache River. A few small streams flow eastward into the Hatchie Coon Sunk Lands. The larger streams flow through rather broad valleys with smoothly rounded slopes, and many of the smaller headwater streams occupy deep, steep-sided ravines, producing a rugged topography along the main divides.

The Advance lowland, a plain lying 250 to 260 feet above sea level and inclining slightly to the southward, includes all the county west of Crowleys Ridge; this lowland is characterized by irregularly distributed patches of grass-covered, gently undulating prairie land and tracts of wooded land. The valley of Cache River, which crosses the western part of the county from northeast to southwest, is 8 to 10 feet lower than the general level and is 1 to 4 miles wide. The valley of Bayou De Vue, which heads in Crowleys Ridge north of Jonesboro and flows across the plain from northeast to southwest, west of the St. Louis Southwestern Railway, is also broad and very shallow.

All the county east of Crowleys Ridge is included in the Mississippi lowland which is divisible into the post-oak flats, a narrow strip of slightly undulating land bordering Crowleys Ridge and lying 255 to 260 feet above sea level, and the "sunk lands," which lie 10 to 15 feet lower and embrace the remainder of the county to the east. The "sunk lands" are gently undulating, the partly wooded, swampy depressions being separated by low ridges of dark sandy

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loam dotted with the so-called sand blows of the region. The sand blows are low circular or irregular patches of clean white sand, supposed to have been discharged from underground sources through crevices during the time of the New Madrid earthquake shocks (1811–12). The ridges have been partly cleared and cultivated.

GEOLOGY.

Irregularly bedded sands and clays belonging to the Wilcox formation of the Eocene make up the body of Crowleys Ridge to a maximum height of 100 feet or more above the level of the lowlands to the east and west. Along the western border of the ridge the sands have been locally indurated to hard quartzites. In Crowleys Ridge the Eocene deposits extend to an unknown depth, and are believed to underlie the alluvial deposits both to the east and west of the ridge, where they would be encountered at depths of 130 to 150 feet; they contain important water-bearing beds.

From general considerations it is believed that the Eocene deposits are underlain by sands and clays of Cretaceous age, though no data for definitely differentiating the deeply buried deposits of these ages have been obtained within the county.

The Wilcox formation of Crowleys Ridge is unconformably overlain by irregularly bedded gravels and reddish sands reaching a maximum thickness of 50 feet or more; these materials cap the tops of the hills and mantle their slopes, almost completely covering the Wilcox strata; they are in part water bearing. These gravels and sands belong to the Lafayette formation and are of late Pliocene or early Pleistocene age. The Lafayette formation is overlain by material ranging in composition from typical loess to reddish loesslike clays and in thickness from a few feet to 40 feet; the loess is of Pleistocene age.

The advance lowland west of Crowleys Ridge is underlain by 130 to 150 feet of alluvial sands, clays, and gravels of Pleistocene age, which rest upon Tertiary strata; the sands and gravels contain water in large quantities. The flood plains of Cache River and Bayou De Vue are underlain by Recent alluvial sands and clays of undetermined thickness which rest upon the Pleistocene alluvium. The Mississippi lowland east of Crowleys Ridge is underlain to an estimated depth of 130 to 200 feet by undifferentiated alluvial sands, clays, and gravels of Pleistocene and Recent age, which rest on Eocene strata and are abundantly water bearing.

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WATER RESOURCES.

GENERAL CONDITIONS.

Domestic supplies.—Water for domestic and industrial use is obtained chiefly from wells 10 to 200 feet deep and from springs. In the lowlands east and west of Crowleys Ridge the waters are derived chiefly from the Pleistocene and Recent alluvial sands and gravels and stand in the wells 10 to 35 feet below the surface. In Crowleys Ridge the wells tap the water-bearing sands and gravels of the Lafayette formation and the water-bearing sands of the underlying Wilcox formation; the waters from the Wilcox formation rise within 25 to 100 feet of the surface. Most of the well waters are soft, though a few are reported to be moderately hard. Wells exceeding 200 feet in depth have been drilled at Jonesboro and at Lake City (Nos. 10, 11, and 15, p. 172). Small springs are numerous in Crowleys Ridge and afford clear, soft, or only moderately hard waters; some are sulphurous or ferruginous.

In the lowlands west and east of Crowleys Ridge water in abundance is contained in the sands and gravels of the Pleistocene and Recent alluvial deposits at depths of 30 to 150 feet. In Crowleys Ridge moderate or large quantities of artesian water can be obtained from the Eocene deposits and from the deeply buried Cretaceous deposits by wells 70 to 1,500 feet or more in depth. In the lowlands artesian waters can be obtained from the same deposits by drilling through the overlying Recent or Pleistocene alluvium.

None of the wells in this county yield flowing water, but the fact that flows have been obtained in Mississippi County at Blythesville (depth, 1,448 feet), at Burdette (depth, 1,495.5 feet), and at Wilson (depth, 1,568 feet), and in Poinsett County at Marked Tree (depth, 2,007 feet) justifies the prediction that flows are obtainable in Craighead County in the Mississippi lowlands east of Crowleys Ridge.

Irrigation.—The rice-growing industry has been introduced in the county in recent years and on the Advance lowland west of Crowleys Ridge is rapidly becoming important. Rice has also been grown east of Crowleys Ridge near Nettleton. Water for irrigating the rice fields is obtained chiefly from wells 75 to 150 feet deep, the source being the Pleistocene alluvial sands and gravels underlying the lowlands. Heavy machinery is used for pumping the wells, the yield ranging from 400 to 1,600 gallons per minute. The wells are drilled and equipped at costs ranging from $1,000 to $1,500, the average cost based on six wells being in round numbers $1,400 for each 1,000 gallons of yield per minute, or at the rate of $1.40 for each gallon of yield per minute. Detailed information concerning nine wells used for irrigating rice lands is given in the table on page 172.

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LOCAL SUPPLIES.

Jonesboro.—The municipal water supply of Jonesboro (population 7,123, census of 1910) is taken from deep wells. Information concerning the system has been obtained from Mr. Jeffrey A. Houghton, postmaster of Jonesboro; from the superintendent of the waterworks plant; and from Mr. Lee Stone, who drilled the two deepest wells. There are six wells, four of which are 300 to 500 feet deep, and two respectively 1,214 and 1,265 feet deep. One of the deepest wells is cased to a depth of 500 feet with 8-inch casing and the rest of the way with 6-inch casing; the other is cased to a depth of 500 feet with 6-inch casing and the remainder of the depth with 4-inch casing; in these wells the water rises to within 60 feet of the surface.

The water is pumped from the wells to a standpipe, the base of which is 372 feet above sea level and 70 feet above the level of the St. Louis Southwestern Railway track at the station. The water is distributed through nearly 15 miles of mains. The standpipe pressure is 72 pounds per square inch and the possible direct pressure for fire protection is 110 pounds per square inch. The daily capacity of the plant is 2,000,000 gallons.

An approximate log of one of the deep wells (No. 10, p. 172) is as follows:

Log of deep well at the city waterworks plant, Jonesboro.

	Thickness.	Depth.
Pleistocene:	*Feet.*	*Feet.*
Red clay (a facies of the loess)	20	20
Pliocene (?) (Lafayette formation):		
Gravel mixed with red clay	4	24
Joint clay	10	34
Coarse yellow sand	1	35
Eocene and probably Cretaceous (undifferentiated):		
Pipe clay	25	60
Gumbo	10	70
Very fine quicksand, grading downward to a coarse sand and gravel, the latter abundantly water bearing	60	130
Very tough black gumbo	50	180
Blue mud, soft in places, containing iron concretions called "niggerheads"	1,020	1,200
Very hard rock	4	1,204
Alternating layers of water-bearing sand and hard rock, the sand layers being about 14 feet thick and the rock layers 1 to 2 feet thick	61	1,265

The log of a well owned by Mr. C. N. Carson, 4 miles south of Jonesboro, on the east side of Crowleys Ridge (No. 12, p. 172), is as follows:

Log of well of C. N. Carson, 4 miles south of Jonesboro.

	Thickness.	Depth.
Pleistocene (?):	*Feet.*	*Feet.*
Red clay	7	7
Eocene (Wilcox formation):		
White sand, water bearing in basal portion	107	114

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Nettleton.—Detailed information concerning several wells at Nettleton (population 1,080, census of 1910) is given in the table on page 172 (Nos. 16, 17, 18). A log of the well owned by the St. Louis, Iron Mountain & Southern Railway is as follows:

Log of well of St. Louis, Iron Mountain & Southern Railway, Nettleton.

	Thickness.	Depth.
Pleistocene alluvium (?):	Feet.	Feet.
Yellowish clay	24	24
Fine white sand, water bearing	40	64
Coarse sand and gravel	3	67
Yellowish, tough clay	20	87
Yellowish, white, pink, and gray sand, gravel at bottom, water bearing throughout	60	147

Greensboro.—The log of a well (No. 9, p. 172) owned by J. W. Johnson at Greensboro, a small village on Crowleys Ridge, 8 miles northeast of Jonesboro, is as follows:

Log of well of J. W. Johnson, Greensboro.

	Thickness.	Depth.
Soil and Pleistocene (a facies of loess):	Feet.	Feet.
Soil and underlying loess	10	10
Pliocene (?) (Lafayette formation):		
Gravel	1	11
Tertiary (Eocene, Wilcox formation):		
Clay ("hardpan")	30	41
Sand, reddish at top, becoming white toward base; water bearing in basal portion	145	186

Lake City.—A 400-foot oil-prospecting well was drilled at Lake City in 1900 (?), concerning which the following information has been furnished by Mr. A. J. Bates: Sands and clays in alternating layers, with the sands predominating, were penetrated to the bottom of the well, with the exception of a bed of gravel encountered at a depth of 300 feet. An incomplete set of samples from the well was examined by the senior author. From the surface to a depth of 130 feet the materials appear to be alluvial sands and clays. A sample from a depth of 160 feet is medium-grained white sand; one from a depth of 220 feet is hard white clay breaking with a conchoidal fracture; and one from a depth of 280 feet is black, shiny lignite. The strata from 160 feet to 400 feet probably belong to the Wilcox formation.

Wells for irrigation.—Wells used for irrigating rice lands have been drilled in the vicinity of Bono, Gilkeson, Obear, and Nettleton; nine of them are described in detail in the table on pages 172–173. The logs of four of them are as follows:

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Log of well of J. E. Bobbitt, 1 mile north of Bono.

[No. 1, p. 172.]

	Thickness.	Depth.
Soil and Pleistocene alluvium:	*Feet.*	*Feet.*
Soil	2	2
"Hardpan"	18	20
Gravel, water bearing	58	78

Log of well of Burk & Cole, 2½ miles southwest of Gilkeson.

[No. 7, p. 172.]

	Thickness.	Depth.
Soil and Pleistocene alluvium:	*Feet.*	*Feet.*
Soil	2.5	2.5
"Hardpan"	18	20.5
Quicksand	35	55.5
Coarse sand, water bearing	10	65.5
Gravel, water bearing	37.5	103

Log of well of C. O. Collins, 7 miles southwest of Jonesboro (3 miles southeast of Gilkeson).

[No. 13, p. 172.]

	Thickness.	Depth.
Soil and Pleistocene alluvium:	*Feet.*	*Feet.*
Soil	2	2
Hard clay called "hardpan"	20	22
Soft friable clay	10	32
Fine sand	5	37
Sand, increasing in coarseness to a very coarse gravel at base, water bearing throughout	76	113

Log of well of the Gregg & Houghton Land Co., 3½ miles northwest of Obear.

[No. 22, p. 172.]

	Thickness.	Depth.
Soil and Pleistocene alluvium:	*Feet.*	*Feet.*
Soil	2	2
"Hardpan" clay	18	20
Fine quicksand	15	35
Coarse sand, water bearing	67	102

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Wells in Craighead County

	Location: Place	T	R	Sec.	Owner	Driller	Authority	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	Geologic name of water-bearing formation
									Feet	Feet	Inches	Feet	Feet	
1	Bono, 1 mile north of	15 N.	4 E.	10, NE. ¼ of NE. ¼	J. F. Bobbitt	Weiner Well Co., Weiner	Owner	1910	[illegible]	[illegible]	[illegible]	[illegible]		Pleistocene alluvium
2	Bono, 5½ miles north east of				W. H. Schisler		J. Q. Schisler		[illegible]	[illegible]	[illegible]			Wilcox (?) formation
3	Bono, one-half mile northwest of	15 N.	3 E.	10	J. D. Stringer	Weiner Well Co., Weiner	Owner	1910	[illegible]	[illegible]	[illegible]			Pleistocene alluvium
4	Brookland				Town	Stone Bros., Jonesboro			[illegible]	184				Wilcox formation
5	Dee, one-fourth mile southeast of	14 N.	4 E.	20, NE. ¼	Wm. Woodard	John Martin, Jonesboro	Owner	1909	[illegible]	108	8	100 108		Wilcox (?) formation
6	Dee				J. F. McCarty					[illegible]				Do.
7	Gilkeson, 2½ miles southeast of	14 N.	3 E.	8, SE. ¼	Burk & Cole, Jonesboro	George Fogle, Jonesboro	J. W. H. Cole	1911	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	Pleistocene alluvium
8	Gilkeson, 3½ miles southeast of	14 N.	3 E.	18, NE. ¼ of SW. ¼	Ellis & Peters, Jonesboro	do	G. C. Peters	1909	[illegible]	[illegible]	10	[illegible]		Do.
9	Greenboro				J. W. Johnson	John Martin, Jonesboro	Owner		[illegible]	[illegible]				Wilcox formation
10	Jonesboro				Town	Lee Stone			[illegible]	[illegible]	[illegible]			Cretaceous
11	do				do	do			[illegible]	[illegible]	[illegible]			Do.
12	Jonesboro, 4 miles south of				C. N. Carson					114				Wilcox formation
13	Jonesboro, 7 miles southwest of	13 N.	3 E.	9, NE. ¼	C. O. Collins	F. L. Casper, Weiner	Owner	1911	[illegible]	118	7½	87 118		Pleistocene alluvium
14	Jonesboro				Warner Hotel					[illegible]				Wilcox formation
15	Lake City						A. J. Bates			[illegible]				
16	Nettleton				St. Louis, Iron Mountain & Southern Ry. Co.		Frank Kiech		[illegible]	147		87 147	94 [illegible]	Pleistocene alluvium (?)
17	do				do		do		[illegible]	[illegible]				Do.
18	Nettleton, one-fourth mile east of	14 N.	4 E.	26	F. Kiech Mfg. Co.	C. H. Winters, Harrisburg	C. W. Kiech	1910	[illegible]	148	10	75 148		Do.
19	Obear, one-fourth mile northwest of				J. L. Burns, Jonesboro	Craighead County Well Co., Jonesboro	Owner	1910	[illegible]	100	10	90 100		Pleistocene alluvium
20	do				do	F. L. Casper, Weiner	do	1911	[illegible]	148	10	90 148		Do.
21	Obear				Barger Bros.					[illegible]				Do.
22	Obear, 3½ miles northeast of	13 N.	3 E.	18, NE. ¼	Gregg & Houghton Land Co., Jonesboro	George Fogle, Jonesboro	C. B. Gregg	1910	[illegible]	109	[illegible]	[illegible]		Do.

a Elevation about 40 feet above the level of the St. Louis, Iron Mountain & Southern Ry. track at the station.

	Location.				Character of principal water-bearing bed.	Level of water below surface.	Yield per minute.	Method of lift.	Cost of well.	Cost of machinery.	Use.	Quality of water.	Remarks.
	Place.	T.	R.	Sec.									
						Feet.	*Gallo.*						
1	Bono, 1 mile north of.	15 N.	3 E.	19, NE. ¼ of NE. ¼.	Gravel	17	400±		$1,500		Irrigation		Analysis 10, p. 302.
2	Bono, 5½ miles northeast of.				Sand						Domestic	Hard	Bored type.
3	Bono, one-half mile northwest of.	15 N.	3 E.	19		10	1,200				Domestic and irrigation.		
4	Brookland				Sand and gravel	25					Domestic		Driven type. Assay 5, p. 304.
5	Dee, one-fourth mile southeast of.	13 N.	4 E.	20, NE. ¼	Sand	97					do	Soft	Bored type. Cribbed with wood.
6	Dee										do		Assay 7, p. 304.
7	Gilkeson, 2½ miles southeast of.	13 N.	3 E.	8, SE. ¼	Coarse sand and gravel.	26	1,600	Steam.	1,028		Domestic and irrigation.		53 feet of 9⅝-inch casing and 9⅝-inch brass screen, analysis 11, p. 302.
8	Gilkeson, 3½ miles southeast of.	13 N.	3 E.	18, NE. ¼ of SW. ¼.	Sand and gravel	27	1,200	do	1,300		do	Hard	72 feet of 10-inch casing and 50 feet of 10-inch Stancliff strainer No. 17. Irrigates 165 acres.
9	Greenboro					36					Domestic		Assay 8, p. 304.
10	Jonesboro					60(?)					Municipal supply.		These wells and 4 others, ranging in depth from 300 to 500 feet, furnish the municipal water supply. Assay 10, p. 304.
11	do					60					do		
12	Jonesboro, 4 miles south of.				White sand	90					Domestic	Soft	
13	Jonesboro, 7 miles southwest of.	13 N.	3 E.	9, SE. ¼	Coarse sand and gravel.	35	800	Gas	1,000	1,000	Domestic and irrigation.		20 feet of 7¼-inch casing and 55 feet of 7¼-inch screen.
14	Jonesboro										Domestic		Assay 11, p. 304.
15	Lake City												Oil prospecting well.
16	Nettleton				Sand and gravel						Boilers		Assay 14, p. 304.
17	do				do						do		
18	Nettleton, one-fourth mile east of.	14 N.	4 E.	26	Sand	15	500+		1,400+		Irrigation		Analysis 12, p. 302.
19	Obear, one-fourth mile northwest of.				Sand and gravel	30.5	600				do		60 feet of 10-inch casing and 40 feet of 10-inch strainer.
20	do				do	30.5	1,000	Steam			do		98 feet of 10-inch casing and 50 feet of 10-inch strainer. Analysis 13, p. 302.
21	Obear					30					Boilers		Assay 15, p. 304.
22	Obear, 3½ miles northeast of.	13 N.	3 E.	18, NE. ¼	Sand		800	Steam	1,000	250	Irrigation		52 feet of 9⅝-inch casing and 50 feet of 9⅝-inch screen. Analysis 14, p. 302.

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Wells in Craighead County.

	Location.				Owner.	Driller.	Authority.	Date completed.	Approximate elevation above sea level.	Depth.	Diameter.	Depth to principal water-bearing bed.	Depth to other water-bearing beds.	Geologic name of water-bearing formation.
	Place.	T.	R.	Sec.										
									Feet.	*Feet.*	*Inches*	*Feet.*	*Feet.*	
1	Bono, 1 mile north of	15 N.	3 E.	19, NE. ¼ of NE. ¼.	J. E. Bobbitt	Weiner Well Co., Weiner.	Owner	1910	265±	78	9⅝	70–78		Pleistocene alluvium.
2	Bono, 5½ miles northeast of.				W. R. Schisler		J. Q. Schisler		265±	60	12			Wilcox (?) formation.
3	Bono, one-half mile northwest of.	15 N.	3 E.	19	J. D. Stringer	Weiner Well Co., Weiner.	Owner	1910	265±	76	12			Pleistocene alluvium.
4	Brookland				Town	Stone Bros., Jonesboro.			290±	154				Wilcox formation.
5	Dee, one-fourth mile southeast of.	13 N.	4 E.	20, NE. ¼	Wm. Woodard	John Martin, Jonesboro.	Owner	1902	(a)	103	6	100–103		Wilcox (?) formation.
6	Dee				J. F. McCarty					65				Do.
7	Gilkeson, 2½ miles southeast of.	13 N.	3 E.	8, SE. ¼	Burk & Cole, Jonesboro.	George Fogle, Jonesboro.	J. W. H. Cole	1911	287±	103	9⅝	63–103	35	Pleistocene alluvium.
8	Gilkeson, 3½ miles southeast of.	13 N.	3 E.	18, NE. ¼ of SW. ¼.	Ellis & Peters, Jonesboro.	do	G. C. Peters	1909	287±	122	10	92–122		Do.
9	Greenboro				J. W. Johnson	John Martin, Jonesboro.	Owner		370±	186				Wilcox formation.
10	Jonesboro				Town	Lee Stone			300±	1,265	6(?)			Cretaceous.
11	do				do	do			300±	1,214	4(?)			Do.
12	Jonesboro, 4 miles south of.				C. N. Carson					114				Wilcox formation.
13	Jonesboro, 7 miles southwest of.	13 N.	3 E.	9, SE. ¼	C. O. Collins	F. L. Casper, Weiner.	Owner	1911	290±	113	7½	37–113		Pleistocene alluvium.
14	Jonesboro				Warner Hotel					172				Wilcox formation.
15	Lake City						A. J. Bates			400				
16	Nettleton				St. Louis, Iron Mountain & Southern Ry. Co.		Frank Kiech		259	147		87–147	24–64	Pleistocene alluvium (?).
17	do				do		do		259	200				Do.
18	Nettleton, one-fourth mile east of.	14 N.	4 E.	26	F. Kiech Mfg. Co	C. H. Winters, Harrisburg.	C. W. Kiech	1910	260±	143	10	75–143		Do.
19	Obear, one-fourth mile northwest of.				J. L. Burns, Jonesboro.	Craighead County Well Co., Jonesboro.	Owner	1910	253±	100	10	90–100		Pleistocene alluvium.
20	do				do	F. L. Casper, Weiner.	do	1911	253±	148	10	90–148		Do.
21	Obear				Barger Bros					65				Do.
22	Obear, 3½ miles northeast of.	13 N.	3 E.	18, NE. ¼	Gregg & Houghton Land Co., Jonesboro.	George Fogle, Jonesboro.	C. B. Gregg	1910	250±	102	9⅝	33–102		Do.

a Elevation about 40 feet above the level of the St. Louis, Iron Mountain & Southern Ry. track at the station.

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	Location.				Character of principal water-bearing bed.	Level of water below surface.	Yield per minute.	Method of lift.	Cost of well.	Cost of machinery.	Use.	Quality of water.	Remarks.
	Place.	T.	R.	Sec.									
						Feet.	*Gallons.*						
1	Bono, 1 mile north of.	15 N.	3 E.	19, NE. ¼ of NE. ¼.	Gravel	17	400±		$1,500		Irrigation		Analysis 10, p. 302.
2	Bono, 5½ miles northeast of.				Sand						Domestic	Hard	Bored type.
3	Bono, one-half mile northwest of.	15 N.	3 E.	19		10	1,200				Domestic and irrigation.		
4	Brookland				Sand and gravel	25					Domestic		Driven type. Assay 5, p. 304.
5	Dee, one-fourth mile southeast of.	13 N.	4 E.	20, NE. ¼	Sand	97					do	Soft	Bored type. Cribbed with wood.
6	Dee										do		Assay 7, p. 304.
7	Gilkeson, 2½ miles southeast of.	13 N.	3 E.	8, SE. ¼	Coarse sand and gravel.	26	1,600	Steam.	1,028		Domestic and irrigation.		53 feet of 9⅝-inch casing and 9⅝-inch brass screen, analysis 11, p. 302.
8	Gilkeson, 3½ miles southeast of.	13 N.	3 E.	18, NE. ¼ of SW. ¼.	Sand and gravel	27	1,200	do	1,300		do	Hard	72 feet of 10-inch casing and 50 feet of 10-inch Stancliff strainer No. 17. Irrigates 165 acres.
9	Greenboro					36					Domestic		Assay 8, p. 304.
10	Jonesboro					60(?)					Municipal supply.		These wells and 4 others, ranging in depth from 300 to 500 feet, furnish the municipal water supply. Assay 10, p. 304.
11	do					60					do		
12	Jonesboro, 4 miles south of.				White sand	90					Domestic	Soft	
13	Jonesboro, 7 miles southwest of.	13 N.	3 E.	9, SE. ¼	Coarse sand and gravel.	35	800	Gas	1,000	1,000	Domestic and irrigation.		20 feet of 7½-inch casing and 55 feet of 7½-inch screen.
14	Jonesboro										Domestic		Assay 11, p. 304.
15	Lake City												Oil prospecting well.
16	Nettleton				Sand and gravel						Boilers		Assay 14, p. 304.
17	do				do						do		
18	Nettleton, one-fourth mile east of.	14 N.	4 E.	26	Sand	15	500+		1,400+		Irrigation		Analysis 12, p. 302.
19	Obear, one-fourth mile northwest of.				Sand and gravel	30.5	600				do		60 feet of 10-inch casing and 40 feet of 10-inch strainer.
20	do				do	30.5	1,000	Steam.			do		98 feet of 10-inch casing and 50 feet of 10-inch strainer. Analysis 13, p. 302.
21	Obear					30					Boilers		Assay 15, p. 304.
22	Obear, 3½ miles northeast of.	13 N.	3 E.	18, NE. ¼	Sand		800	Steam.	1,000	250	Irrigation		52 feet of 9⅝-inch casing and 50 feet of 9⅝-inch screen. Analysis 14, p. 302.

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CRITTENDEN COUNTY.

PHYSIOGRAPHY.

Crittenden County, in the eastern part of the State, adjacent to the southwestern part of Tennessee, comprises an area of 582 square miles. The population was reported by the census of 1910 as 22,447. Lumbering and agriculture, including trucking and the raising of cotton and cereals, are the chief industries. Fruit is also grown. The county is heavily timbered and large sawmills are numerous.

The county is included in the Mississippi lowland, the general surface lying 200 to 236 feet above sea level. Mississippi River forms the eastern boundary; the highest land lies immediately west of the river, from which there is a slight inclination to the west and southwest. Ponds, abandoned stream channels, and bayous are numerous, and much of the surface is swampy and covered with forest. The area is subject in part to overflow from Mississippi River. Some of the higher land has been cleared and cultivated. The drainage is chiefly to the southwest into St. Francis River.

GEOLOGY.

The surface materials throughout the county consist of Recent alluvial sands and clays deposited from the waters of Mississippi River. Data concerning the age of the materials below the Recent deposits are meager. It is possible that the Recent alluvium rests on alluvial sands, clays, and gravels of Pleistocene age, which in turn rest on an eroded surface of Tertiary (Eocene) strata. The depth to the Eocene strata has not been determined, but data afforded by several wells probably indicate that the Eocene lies 150 to 225 feet below the general surface.

The undifferentiated Eocene strata are believed to be about 1,000 feet thick and they are underlain by strata of Cretaceous age. According to Ashley's interpretation[1] of the record of a well on Hen and Chicken Island, near Memphis, the Ripley formation of the Upper Cretaceous was first encountered at a depth of 1,135 feet (see section, p. 177), and clay representing the Selma chalk, also Upper Cretaceous, was reached at a depth of 1,589 feet, and had not been completely penetrated when drilling was discontinued at a depth of 1,793 feet. At an unknown depth, probably between 2,500 and 3,000 feet, the Cretaceous deposits are believed to rest upon a basement of Paleozoic rocks.

[1] Ashley, G. H., Recent drilling for oil and gas at Memphis, Tenn.: Preliminary report upon the oil and gas developments in Tennessee: Tennessee Geol. Survey, Appendix A, pp. 40–42, 1911.

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WATER RESOURCES.

GENERAL CONDITIONS.

The domestic water supplies of this county are obtained chiefly from wells 10 to 100 feet deep, the strata drawn upon being the alluvial sands. The water in the wells stands 10 to 30 feet below the surface. As reported by the well owners, some of the waters are soft, some are hard, and some are ferruginous. Wells more than 100 feet deep have been drilled at Earl and Turrell. Cisterns are in use at a few places in the county.

Water in great abundance is obtainable from the sands and gravels of the Recent and Pleistocene alluvial deposits to depths of 150 to 225 feet. The Eocene deposits which underlie the alluvial materials to depths of 1,100 or 1,150 feet contain important water-bearing beds, the waters of which are under hydrostatic pressure and will rise within 5 to 15 feet of the surface or may even overflow at the surface; they will be found potable and suitable for domestic and most other ordinary purposes, but some of them are apt to be moderately hard or ferruginous. The Cretaceous deposits which underlie the Eocene strata also contain water-bearing beds and probably the waters are under sufficient hydrostatic pressure to overflow at the surface.

LOCAL SUPPLIES.

Earl.—The town of Earl (population 1,542, census of 1910) owns a municipal water-supply system and obtains water from a 474-foot well (No. 1, p. 178). The water is lifted from the well by a pump, having a capacity of 17,000 gallons an hour, into a tank holding 40,000 gallons. The tank pressure is 35 pounds per square inch, and the direct pressure for fire protection is 60 pounds per square inch. Three miles of mains distribute the water to the consumers. The daily consumption is 70,000 gallons for domestic use and 50,000 gallons for manufacturing. (See incomplete analysis No. 15, p. 302.)

Turrell.—The following is the log of a deep well at Turrell owned by the Baker Lumber Co.[1] (No. 5, p. 178):

Log of well of Baker Lumber Co., Turrell.

	Thickness.	Depth.
Quaternary alluvium (Pleistocene and Recent):	*Feet.*	*Feet.*
"Buckshot" grading downward into sand	16	16
Sand and gravel with thin clay partings	166	182
Tertiary (Eocene):		
Blue clay with enough fine sand to make sinking by hydraulic process easy	658	840
Gray sand like that at Memphis, containing lignite in large quantities	24	864

[1] Shepard, E. M., Underground waters of Missouri: U. S. Geol. Survey Water-Supply Paper 195, p. 187, 1907.

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Wells at and near Memphis, Tenn.—Several deep wells have been drilled in areas adjacent to Crittenden County, at and near Memphis, Tenn.; the materials penetrated in them are essentially the same as would be encountered by deep drilling anywhere in Crittenden County. Logs of the two deepest wells reported are included here.

Log of municipal well No. 109, Memphis.[a]

	Thickness.	Depth.
	Feet.	*Feet.*
Yellow clay	27	27
Hard brown clay	10	37
Slightly soft brown clay	8.4	45.4
Gravel and sand	4	49.4
Soft brown clay and sand	14	63.4
Slightly hard brown clay	12.5	75.9
Stiff blue clay	3	78.9
Soft blue clay	4.4	83.3
Stiff blue clay and sand	2.6	85.9
Soft brown clay and sand	1	88.9
Very hard brown clay	2	88.9
Very reddish clay	1.5	90.4
Hard blue clay	15.5	105.9
Soft blue clay	15.1	121
Stiff blue clay	1	122
Soft brown clay	4	126
Slightly hard brown clay	1.3	127.3
Stiff brown clay	1	128.3
Hard brown clay	1	129.3
Very hard brown clay	5.7	135
Hard brown clay	61	196
Slightly hard blue clay	18	214
Hard blue clay	9	223
Sandy blue clay	53	276
Fine sand and clay	27	303
Fine sand	35.4	338.4
Fine sand and lumps of blue clay	41.6	380
Coarse sand and lumps of blue clay	10	390
Soft blue clay	17	407
Sandy blue clay	10	417
Fine sand and clay	15	432
Sandy blue clay	13	445
Fine sand and clay	7	452
Sandy blue clay	22	474
Fine sand	2.6	476.6
Sandy blue clay	6.6	483.2
Fine sand	.8	484
Coarse sand and clay	6	490
Soft blue clay	2.3	492.3
Clay and sand	17.7	510
Very fine sand	25	535
Very fine sand and clay	38.2	573.2
Very fine sand	16.8	590
Very coarse sand with lignite	8	598
Lignite, pyrite, and clay	2	600
Very fine sand and lignite	195	795
Soft white clay	17	812
Very fine sand	53	865
Hard brown clay	31	896
Fine white sand	30	926
Hard brown clay	24	950
Fine sand	50	1,000
Stiff brown clay	25.6	1,025.6
Very hard, substantial rock	.5	1,026.1
Very stiff blue clay	27.9	1,054
Blue clay, slightly sandy	106	1,160
Shale	.5	1,160.5
Sandy clay	3.5	1,164
Gravel	6	1,170
Blue clay and sand	26	1,196
Sand and rock	7	1,203
Sand and blue clay	6	1,209
Sand and clay and rock	23	1,232
Fine sand and clay	8	1,240
Blue clay and sand	46	1,286
Sand and clay	79	1,365
Fine sand	35	1,400
White sand (water flowed to surface)	4	1,404
White sand	38	1,442

[a] Glenn, L. C., U. S. Geol. Survey Water-Supply Paper 164, pp. 114, 115, 1906. (Gives a partial log of the well to a depth of 1,147.5 feet.) Munn, M. J., Resources of Tennessee, vol. 2, No. 2, pp. 55–57, Tennessee Geol. Survey, Feb., 1912. (Gives a complete log of the well to a depth of 1,583 feet.)

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Log of municipal well No. 109, Memphis—Continued.

	Thickness.	Depth.
	Feet.	*Feet.*
Blue clay	95	1,537
Good sand	20	1,557
Black sand	6	1,563
Blue clay and sand	3	1,566
Clay	16	1,582
Fine gray sand	1	1,583

Log of Memphis Natural Gas & Oil Co.'s oil-prospecting well No. 1, on Hen and Chicken Island.[a]

	Thickness.	Depth.
	Feet.	*Feet.*
Gray sand	35	35
Clay	3	38
Gas sand	20	58
Blue gumbo	4	62
Fine gray sand	43	105
Fine gravel	4	109
Coarse gravel	12	121
White sand	4	125
Clay and lignite	130	255
Gray water-bearing sand and lignite	221	476
Blue clay (chunks)	70	546
Gray sand and lignite	154	700
Gray coarse water sand	45	745
Gray sand and lignite	225	970
Blue clay	155	1,125
Brown sand (good showing of oil)	10	1,135
Black gas sand (gas and oil showing)	12	1,147
Cemented rock and gravel	1	1,148
Gas sand	24	1,172
Blue rock	3	1,175
Green clay	2	1,177
Brown clay	7	1,184
Lignite	5	1,189
Blue clay	33	1,222
Fine sand	10	1,232
Green clay	23	1,255
Hard clay	45	1,300
Fine sand	4	1,304
Gumbo	20	1,324
Fine sand	27	1,351
Gumbo	8	1,359
Artesian sand	230	1,589
Clay	86	1,675
Fine sand	9	1,684
Clay	16	1,700
Blue rock	5	1,705
Fine sand	3	1,708
Clay	38	1,746
Fine sand	17	1,763
Clay	8	1,771
Fine sand	9	1,780
Gumbo, strong showing of oil; stops on rock	14	1,794

[a] Ashley, G. H., Recent drilling for oil and gas at Memphis: Preliminary report upon the oil and gas developments in Tennessee, Appendix A, pp. 40–42, Tennessee Geol. Survey, 1911.

Ashley says:

Well No. 1 passed through 155 feet of blue clay between 980 feet and 1,135 feet. Apparently this is the Porters Creek clay [basal Eocene]; then comes sand, clay, and lignite, the sand predominating, to 1,589 feet, or for a thickness of 454 feet. As clays predominate below, and as this is about the thickness of the Ripley formation [Upper Cretaceous], it may be assumed to represent that formation; below would come the Selma clay [Upper Cretaceous], and as that formation has a thickness of 300 to 400 feet to the east, it would appear that the well stopped in that formation. The Selma clay is a light leaden gray or greenish clay when dry, and somewhat darker when wet. It will be noted that of the 204 feet of strata at the bottom of the well below 1,589 feet all but 43 feet are clay.

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Wells in Crittenden County.

	Location.				Owner.	Driller.	Authority.	Date completed.	Approximate elevation above sea level.	Depth.	Diameter.	Depth to principal water-bearing bed.	Geologic name of water-bearing formation.
	Place.	T.	R.	Sec.									
									Feet.	*Feet.*	*In.*	*Feet.*	
1	Earl				Town	Johnson & Fleming, Memphis, Tenn.	Sam Boone	1905	231	474	4	414–474	Wilcox (?) formation.
2	Ebony, one-eighth mile north of.	7 N.	8 E.	21, SE. ¼	The Ebony Co	Owner	H. D. Drane		230±	50	1½	50	Quaternary alluvium.
3	Gilmore, 2½ miles west of.	9 N.	7 E.	3	W. A. Dudley	do	Owner	1910	236±	60(?)	1½	50–60(?)	Do.
4	Marion				L. D. Bland		do		231±	78			Do.
5	Turrell	9 N.	8 E.	29	Baker Lumber Co.	Johnson & Fleming, Memphis, Tenn.	W. B. Johnson [a]	1901	236±	864	4	840–864	Wilcox (?) formation.

	Location.				Character of principal water-bearing bed.	Level of water below surface.	Yield per minute.	Method of lift.	Cost of well.	Cost of machinery.	Use.	Quality of water.	Remarks.
	Place.	T.	R.	Sec.									
						Feet.	*Galls.*						
1	Earl				Coarse sand	14½	70+				Municipal supply, manufacturing.		Analysis 15, p. 302.
2	Ebony, one-eighth mile north of.	7 N.	8 E.	21, SE. ¼		20		Gas	$20		Domestic and boilers.		Driven type; on the land owned by the company there are numerous similar wells at the houses of tenants.
3	Gilmore, 2½ miles west of.	9 N.	7 E.	3	Sand			Hand	15		Domestic	Hard	
4	Marion										do		Driven type. Assay 18, p. 304.
5	Turrell	9 N.	8 E.	29	Gray sand	12					do		See log of well on p. 175. Assay 21, p. 304.

[a] Shepard, E. M., Underground waters of Missouri: U. S. Geol. Survey Water-Supply Paper 195, p. 187, 1907.

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CROSS COUNTY.

PHYSIOGRAPHY.

Cross County lies west of Crittenden County and north of St. Francis County. Its area is 619 square miles. Its population at the time of the census of 1910 was 14,042. Lumbering, agriculture, fruit growing, and stock raising are important industries. At Wynne, the county seat, there are several sawmills and mills which manufacture wood products.

The county includes parts of three recognizable physiographic subdivisions—Crowleys Ridge, the Advance lowland, and the Mississippi lowland.

Crowleys Ridge is a belt of hilly, partly wooded land, 3 to 6 miles wide, extending north and south through the center of the county and rising 350 to 380 feet above sea level, or 120 to 150 feet above the lowlands to the east and west. Small intermittent and perennial streams flow at right angles to the trend of the ridge and discharge into St. Francis River or St. Francis Bayou on the east and into L'Anguille River on the west. The surface has been considerably dissected by these streams. The eastern slope is somewhat more abrupt than the western slope, but both margins of the ridge are separated from the bordering lowlands by sharply defined escarpments.

The Advance lowland includes the area west of Crowleys Ridge, a nearly level plain lying 230 to 245 feet above sea level and sloping slightly to the south. It is drained chiefly by L'Anguille River (flowing southward) and its tributaries, which occupy shallow valleys that are only a few feet lower than the general level, are in part swampy, and are heavily timbered except where locally cleared for cultivation. In the interstream areas west of L'Anguille River the surface is gently rolling and presents irregularly distributed tracts of open grass-covered prairie, separated by slightly lower wooded areas. East of L'Anguille River the surface slopes gradually upward from the river bank to the foot of Crowleys Ridge; here the land is more fertile than the land west of the river and is forested, except where locally cleared for cultivation.

The Mississippi lowland east of Crowleys Ridge is within the flood plain of St. Francis River and is 220 to 235 feet above sea level. St. Francis River enters the county at the northeast corner and flows sinuously across it in a general southwesterly direction. Bayou St. Francis enters the county in the north, flows southward near the foot of Crowleys Ridge, and joins St. Francis River near Levesque. The surface of the lowland is diversified by numerous ponds and abandoned stream channels, separated by wooded areas of low swamp land and low ridges.

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GEOLOGY.

The core of Crowleys Ridge to a height of 50 to 100 feet above the lowlands to the east and west is composed of regularly and irregularly bedded fine sands and clays of Eocene age, belonging mainly to the Claiborne formation. The clays are light to dark in color and in places are lignitic. Well-preserved fossil leaves of Claiborne age have been found in clays and nodules of iron carbonate in an exposure near Cherry Valley. (See p. 69.) The Eocene deposits underlie Crowleys Ridge to an undetermined depth, estimated to be at least 1,000 feet; they also underlie the alluvial deposits in the lowlands, both to the east and west of the ridge; they contain important water-bearing beds.

The Eocene deposits are underlain by strata of Cretaceous age, doubtless in part water bearing, which at an unknown depth rest upon a basement of Paleozoic rocks. The Eocene strata in Crowleys Ridge are unconformably overlain by 10 to 40 feet of irregularly bedded sands and gravels of late Pliocene or early Pleistocene age belonging to the Lafayette formation; they are in part water bearing. Locally the gravels have been indurated to a conglomerate. The gravels and sands are overlain by 20 to 60 feet of yellowish, reddish, and brownish massive loess, in part calcareous, which forms the capping material of Crowleys Ridge.

The gravels, sands, and loess extend down over the slopes of the ridge, and doubtless they have been reworked in part from their original position, or have found their way downward by creep or landslides.

The Advance lowland west of Crowleys Ridge is underlain by 140 to 160 feet of alluvial gravels, sands, clays, and loams of Pleistocene age, unconformably overlying Eocene strata. In general the materials grade downward from fine clays and loams to coarse water-bearing sands and gravels at the base. The flood plains of L'Anguille River and its tributaries are underlain by Recent alluvial sands, clays, and loams of undetermined thickness. The Mississippi lowland east of Crowleys Ridge is underlain by 150 to 225 feet of undifferentiated Recent and Pleistocene loams, clays, sands, and gravels which rest unconformably upon Eocene strata. The sands and gravels carry large quantities of water.

WATER RESOURCES.

GENERAL CONDITIONS.

Domestic supplies.—Water for domestic and industrial uses is obtained chiefly from wells 10 to 200 feet deep, and from springs. In the lowlands the sands and gravels of the alluvial deposits form the principal source of the waters; the static head of the wells is 10 to 35 feet below the surface. In Crowleys Ridge the sands and gravels of the Lafayette formation and beds of sand in the underlying Eocene

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deposits yield waters which here rise within 30 to 100 feet of the surface. Wells exceeding 200 feet in depth have been drilled at Wynne, at Parkin, and 5 miles east of Cherry Valley. As reported by the well owners, some of the well waters are soft, some are hard, and some are ferruginous. With perhaps a few exceptions they are potable and are suitable for most ordinary purposes. Numerous small springs in Crowleys Ridge yield soft moderately mineralized waters.

The Pleistocene alluvial deposits, which underlie the Advance lowland west of Crowleys Ridge to depths of 140 to 160 feet, and the undifferentiated Pleistocene and Recent alluvial deposits, which underlie the Mississippi lowland east of the ridge to depths of 150 to 225 feet, contain in their sandy and gravelly layers great quantities of water suitable for domestic and industrial supplies and for irrigation. The Tertiary strata which underlie Crowleys Ridge and upon which rest the alluvial deposits east and west of the ridge contain important water-bearing beds that may be reached by wells at estimated depths of 1,000 to 1,200 feet below the lowland levels. These are underlain to unknown depths by deposits of Cretaceous age which also contain water-bearing beds.

There are no flowing wells in the county. In the two deep wells at Parkin (480 and 597 feet, respectively), the water rises within 10 to 12 feet of the surface and a well 2,007 feet deep at Marked Tree, Poinsett County, overflows at the surface, facts which seem to show that flows could be obtained in this county in the Mississippi lowland east of Crowleys Ridge at depths of 1,800 to 2,500 feet.

Irrigation.—The rice-growing industry has been introduced into the county and in the flat lands west of Crowleys Ridge is rapidly becoming important. Water for irrigation is obtained chiefly from wells 65 to 170 feet deep which tap the water-bearing alluvial sands and gravels underlying the Advance lowland, and yield from 500 to 2,000 gallons per minute. The cost of drilling and equipping the wells ranges from $550 to $1,200 per well, the average cost for five wells being $1,100 for each 1,000 gallons of yield per minute, or at the rate of $1.10 for each gallon of yield. Six irrigation wells are described in the table on page 184.

LOCAL SUPPLIES.

Wynne.—The town of Wynne (population 2,353, census of 1910) owns a municipal water-supply system and obtains water from two 125-foot wells (Nos. 17, 18, p. 184). C. M. Crain, mayor, has furnished the following information in regard to the wells and plant: The water is pumped from the wells to a standpipe having a capacity of 75,000 gallons and furnishing a standpipe pressure of 75 pounds per square inch. The water is distributed to the consumers through 4 miles of mains, the daily consumption for domestic purposes being approximately 65,000 gallons.

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One well at Wynne has been sunk to a depth of 360 feet. The name of the owner and other details have not been obtained, but a citizen has furnished the following log which, since it is given from memory, must be understood as only approximately correct:

Log of well at Wynne.

	Thickness.	Depth.
Pleistocene (a facies of loess):		
Yellow loam	Feet. 40	Feet. 40
Tertiary (Eocene):		
White to gray, tough clay	15	55
Red "buckshot" clay	9	64
Red, blue, and white sand, very fine on top and becoming coarse below; water bearing. Water potable but hard and scales boilers	25	89
Fine white sand	25	114
Black and white sand, water bearing; water hard, but scales boilers less than that from layer 5; fossils reported from the sand	20	134
Coarse white sand with a layer of gravel within 5 feet of top, water bearing; water of better quality for drinking and for boiler-supply purposes than that from layers 3 and 5	30	164
Gray, tough "pipe" clay	196	360

The Wynne Brick Co. owns a well 250 feet deep (No. 19, p. 184) and the St. Louis, Iron Mountain & Southern Railway Co. owns a well 186 feet deep (No. 16, p. 184).

Parkin.—Two deep wells, the deepest in the county, have been drilled at Parkin. One, owned by the Northern Ohio Cooperage & Lumber Co., is 597 feet deep (No. 10, p. 184), the log of which is as follows:

Log of well of the Northern Ohio Cooperage & Lumber Co., Parkin.

	Thickness.	Depth.
Quaternary alluvium:		
Not reported	Feet. 80	Feet. 80
Sand	100	180
Gravel, water bearing	40	220
Tertiary (Eocene—probably in part Claiborne and in part Wilcox):		
Clay	375	595
Sand, water bearing	2	597

The other well, owned by the Lansing Wheelbarrow Co., is 480 feet deep (well 9, p. 184).

Vanndale.—A 167-foot well at Vanndale is owned by the York Lumber Co. (No. 13, p. 184). The following log has been furnished by Mr. Wiley, of the firm of Layne & Bowler, drillers, Stuttgart, Ark., through Mr. E. G. Norton, of Brinkley, Ark.:

Log of well of the York Lumber Co., Vanndale.

	Thickness.	Depth.
[Pleistocene alluvium]:		
Clay	Feet. 65	Feet. 65
Fine sand	52	117
Fine gravel	12	129
Coarse gravel, water bearing; stopped drilling on blue clay	38	167

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Five miles east of Cherry Valley.—A well located near the east foot of Crowleys Ridge, owned by Mr. Smith, is 230 feet deep. The owner has furnished the following log from memory:

Log of well owned by Mr. Smith, 5 miles east of Cherry Valley.

[No. 3, p. 184.]

	Thickness.	Depth.
[Quaternary (alluvium)]:	*Feet.*	*Feet.*
Sandy loam	1.5	1.5
Sand and gravel	15	16.5
[Tertiary (Eocene)]:		
Sand, alternating with layers of sticky clay	213.5	230

Fairoaks.—A well at Fairoaks, 82 feet deep, is owned by the St. Louis Southwestern Railway Co. (No. 4, p. 184). The log is as follows:

Log of well of the St. Louis Southwestern Railway Co., Fairoaks.

	Thickness.	Depth.
Pleistocene alluvium:	*Feet.*	*Feet.*
White earth	3	3
"Hardpan"	9	12
Gray medium fine sand, water bearing	70	82

Wells for irrigation.—Wells for irrigating rice lands have been drilled in the vicinity of Cherry Valley, Fairoaks, Hickory Ridge, Hydrick, Tilton, and Vanndale; six of the wells are described in detail in the table on page 184. Logs of three of them are as follows:

Log of well of T. A. Norviel, 2.5 miles east of Fairoaks.

[No. 5, p. 184.]

	Thickness.	Depth.
Pleistocene alluvium:	*Feet.*	*Feet.*
Clay	14	14
Sand, water bearing	26	40
Coarse gravel, water bearing	25	65

Log of well owned by W. F. Clements, near Hydrick.

[No. 7, p. 184.]

	Thickness.	Depth.
Pleistocene alluvium:	*Feet.*	*Feet.*
Whitish colored clay	40	40
Sand, water bearing, especially in lower 15 feet	35	75

Log of well owned by Miller & Son, 4 miles northeast of Tilton.

[No. 11, p. 184.]

	Thickness.	Depth.
Pleistocene alluvium:	*Feet.*	*Feet.*
Clay and sand	23	23
Quicksand, water bearing	30	53
Sand and gravel, water bearing	27	80

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Wells in Cross County.

	Location.				Owner.	Driller.	Authority.	Date completed.	Approximate elevation above sea level.	Depth.	Diameter.	Depth to principal water-bearing bed.	Depth to other water-bearing beds.	Geologic name of water-bearing formation.
	Place.	T.	R.	Sec.										
									Feet.	*Feet.*	*Inches*	*Feet.*	*Feet.*	
1	Cherry Valley				St. Louis, Iron Mountain & Southern Ry. Co.		J. R. Stephens, chief engineer.		292±	140	10			Pleistocene alluvium.
2	Cherry Valley, one-half mile north of.	9 N.	3 E.	15, NW. ¼ of NE. ¼.	J. O. Halk	J. M. Stacey	Owner	1911		70	2			Pleistocene alluvium (?).
3	Cherry Valley, 5 miles east of.				Mr. Smith	C. H. Winters	do			230				Eocene.
4	Fairoaks				St. Louis Southwestern Ry. Co.	Homer Shults, Pine Bluff.	Driller	1909	218	82	8	21–82		Pleistocene alluvium.
5	Fairoaks, 2½ miles east of.				T. A. Norviel	F. A. Schairman, Jonesboro.	Owner		220±	65	10	18–65		Do.
6	Hickory Ridge, 3½ miles southeast of.	9 N.	1 E.	36, NW. ¼.	Love Banks, Smithdale.	J. E. Gidrey, Rayne, La.	do	1910	235±	121	9⅝	82–121	45	Do.
7	Hydrick	9 N.	3 E.	2, NW. ¼.	S. A. Clements	S. J. Hodges, Harrisburg.	do	1891	(a)	85	2	20–85		Do.
8	do	9 N.	3 E.	2, NW. ¼.	W. F. Clements		do	1908	(b)	75	2½	60–75		Do.
9	Parkin, one-fourth mile south of.	7 N.	5 E.	3, NW. ¼.	Lansing Wheelbarrow Co.		D. S. Watrons.	1902. (?)	220±	480	6			Wilcox (?) formation.
10	Parkin, one-fourth mile north of.	7 N.	5 E.	3, E. ½	Northern Ohio Cooperage & Lumber Co.	W. G. Lanham, Memphis, Tenn.	S. W. Sterling		230±	597	5⅝	597	180–220	Do.
11	Tilton, 4 miles northeast of.	8 N.	1 E.	11, SE. ¼.	Miller & Son	Owner	E. M. Miller	1911	222±	80	6	23–80		Pleistocene alluvium.
12	Tilton, 3½ miles southeast of.	8 N.	1 E.	22, SE. ¼.	B. V. Rogers	Jesse Rogers	Owner	1911	222±	96	8½	31½–96		Do.
13	Vanndale, 2 miles southwest of.				York Lumber Co.	Layne & Bowler, Stuttgart.	E. G. Norton, Brinkley.		260±	167				Do.
14	Vanndale, 7 miles west of.	8 N.	2 E.	2, SW. ¼.	J. W. Blue	Owner	Owner	1910		102	10	80–102		Do.
15	Wynne									360				Wilcox (?) formation.
16	do				St. Louis, Iron Mountain & Southern Ry. Co.		J. R. Stephens, chief engineer.		259±	186	10			Do.
17	do				Town		C. M. Crain	1900	260±	125	6	100		Pleistocene alluvium (?).
18	do				do		do	1900	260±	125	6	100		Do.
19	do				Wynne Brick Co.				260±	250				Wilcox (?) formation.

a Elevation about 35 feet above low-water level of L'Anguille River.

b Elevation about 25 feet above low-water level of L'Anguille River.

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	Location.				Character of principal water-bearing bed.	Level of water below surface.	Yield per minute.	Method of lift.	Cost of well.	Cost of machinery.	Use.	Quality of water.	Remarks.
	Place.	T.	R.	Sec.									
						Feet.	*Gallons.*						
1	Cherry Valley										Boilers		Analysis 16, p. 302.
2	Cherry Valley, one-half mile north of.	9 N.	3 E.	15, NW. ¼ of NE. ¼.	Sand			Hand.	$20	$30	Domestic	Hard	
3	Cherry Valley, 5 miles east of.				do	30					do		
4	Fairoaks				Fine sand	21	300	Steam.			Domestic and boilers.	Ferruginous	Pit 21 feet deep and 12 feet in diameter, lined with cast-iron curbing; 61 feet of 8-inch casing.
5	Fairoaks, 2½ miles east of.				Sand and gravel	18	500		1,000		Irrigation		Analysis 17, p. 302.
6	Hickory Ridge, 3½ miles southeast of.	9 N.	1 E.	36, NW. ¼	Coarse sand and gravel.	26	1,500	Steam.	1,050	700	Domestic and irrigation.		Analysis 18, p. 302.
7	Hydrick	9 N.	3 E.	2, NW. ¼					35		Domestic	Hard	
8	do	9 N.	3 E.	2, NW. ¼	Fine sand	60	10	Hand.	10	25	do	Ferruginous	
9	Parkin, one-fourth mile south of.	7 N.	5 E.	3, NW. ¼		10		Steam.			Domestic and boilers.		Supplies 35 buildings and 600 people.
10	Parkin, one-fourth mile north of.	7 N.	5 E.	3, E. ½	Sand	12	200	do			do	Sulphurous	Supplies 75 buildings and 250 people.
11	Tilton, 4 miles northeast of.	8 N.	1 E.	11, SE. ¼	Sand and gravel		500		400	150	Irrigation	Hard	57 feet of 6-inch casing and 20 feet of 6-inch screen.
12	Tilton, 3½ miles southeast of.	8 N.	1 E.	22, SE. ¼	do	31½	1,200	Steam.	500	225	do		Pit 35 feet deep and 5½ feet square; 42 feet of 8¼-inch casing, and 19 feet of 8¼-inch Keystone screen.
13	Vanndale, 2 miles southwest of.				Coarse gravel						do		
14	Vanndale, 7 miles west of.	8 N.	2 E.	2, SW. ¼	Sand and gravel	30	2,000	Steam.	1,000	185	Drinking and irrigation.		Analysis 21, p. 302.
15	Wynne				Sand							Hard	
16	do										Boilers		This well and 2 similar wells yield 3,000,000 gallons per month. Analysis 22, p. 302.
17	do				Gravel and sand	90		Steam.			Municipal supply.	Alkaline	The amount used daily is approximately 65,000 gallons.
18	do				do	90		do			do	do	
19	do					100						Hard	

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GREENE COUNTY.

PHYSIOGRAPHY.

Greene County lies immediately south of Clay County, in the northeastern part of the State. The area of the county is 561 square miles, and the population was reported by the census of 1910 as 23,852. Agriculture and lumbering are the chief industries, and stock raising is growing in importance. At Paragould, the county seat, are several sawmills and mills manufacturing wood products.

The county includes parts of Crowleys Ridge, the Advance lowland, and the Mississippi lowland, the three main topographic divisions recognizable in the Mississippi embayment.

Crowleys Ridge forms a belt of hilly, partly cultivated and partly wooded land, 8 to 12 miles wide, extending northeast and southwest through the center of the county, attaining a maximum elevation of 500 to 525 feet above sea level, or 200 to 250 feet above the lowlands to the east and west. The ridge is drained by numerous small perennial and intermittent streams which flow either eastward into the Hatchie Coon Sunk Lands or westward into Cache River. The surface has been strongly dissected by these streams, the main ones flowing through rather broad valleys with smoothly rounded slopes; many of the small headwater branches occupy narrow, steep-sided gorges. The main divide of the ridge is a little west of the center and the western slope is in general more rugged than the eastern.

The county west of Crowleys Ridge is included within the Advance lowland, a gently undulating plain lying 260 to 275 feet above sea level and inclining slightly to the south. Cache River flows southwestward in the northwestern part of the county, south of which it forms the western boundary for about 15 miles; the river valley, which is 3 to 5 miles wide and is 8 or 10 feet lower than the general level, is in part swampy and is largely covered with a growth of timber. The interstream areas belong chiefly to the post-oak flat type and are poorly drained. In the northwest, between Cache River and the St. Louis, Iron Mountain & Southern Railway, the otherwise nearly level surface is broken by Jones Ridge, a ridge 3 or 4 miles long, one-quarter to one-half mile wide, and 30 to 40 feet high, which trends northeast-southwest. Between Cache River and the foot of Crowleys Ridge the soil is more fertile than west of the river because of the loams brought down from Crowleys Ridge and deposited on the plain.

All the county east of Crowleys Ridge is included in the Mississippi lowland; immediately east of and bordering the ridge is a belt of post-oak flats, several miles wide, lying 270 to 275 feet above sea level, and crossed by the numerous shallow valleys of the small streams

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from Crowleys Ridge. East of these flats is the "sunk lands" of St. Francis River bottom, a swampy, timber-covered tract several feet lower than the post-oak flats, interspersed with low ridges of sandy loam trending northeast and southwest; the ridges, which have been partly cleared for cultivation, are dotted with the so-called sand blows of the region, which consist of irregularly distributed small patches of clean white sand believed to have been ejected from fissures at the time of the New Madrid earthquake in 1811–12. The "Hatchie Coon Sunk Lands" form the eastern boundary of the county.

GEOLOGY.

The core of Crowleys Ridge to a height of 75 to 100 feet or more is composed of irregularly bedded sands and clays belonging to the Wilcox formation (Eocene). The sands have been locally indurated to sandstones of all grades of hardness from soft, friable rocks to hard quartzites, which outcrop at numerous places along the western slope of the ridge; fossil leaves of Wilcox age have been collected from soft sandstone near Hardys Mill, about 4 miles west of Gainesville. (See p. 59.) Lignite has been encountered in wells drilled at numerous places on the ridge. Eocene strata underlie Crowleys Ridge to a depth estimated to be not less than 400 or 500 feet, and are also present beneath the alluvial deposits both to the east and west of the ridge, where their upper surface lies at depths of 150 to 200 feet; they contain important water-bearing beds. The Eocene strata are believed to be underlain by strata of Cretaceous age, doubtless in part water bearing, which at an undetermined depth, probably not exceeding 1,200 feet, rest on a basement of Paleozoic rocks.

The Eocene strata in Crowleys Ridge are overlain unconformably by a few feet to 50 feet of gravels and reddish sands belonging to the Lafayette formation (Pliocene?); these are in part water bearing. The gravels are locally indurated to conglomerates. The Lafayette formation is overlain by 10 to 30 feet or more of loess presenting various facies of reddish and yellowish argillaceous loam and sandy clay. In places on the crest of the ridge the loess has been completely removed from above the gravels by erosion. Both the loess and gravels extend down over the slopes of the ridge, probably in part reworked and in part as creep materials, almost completely concealing the Eocene strata.

The Advance lowland west of Crowleys Ridge is underlain to an estimated depth of 150 to 175 feet by alluvial gravels, sands, clays, and loams, for the most part of Pleistocene age but in part of Recent age, which rest upon Eocene strata. The Recent alluvium underlies the bottom lands of Cache River to an undetermined depth and the Pleistocene alluvium outcrops in the interstream areas. In general,

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the Pleistocene deposits grade downward from fine clays and silts at the surface through fine sands to coarse sands and gravels at the base, which are abundantly water bearing. The Mississippi lowland is underlain to an estimated depth of 150 to 200 feet by alluvial loams, clays, sands, and gravels of undifferentiated Pleistocene and Recent age. The coarser materials carry water in large quantities.

WATER RESOURCES.

GENERAL CONDITIONS.

Domestic water supplies are obtained chiefly from wells 10 to 130 feet deep. In Crowleys Ridge the wells tap the water-bearing sands and gravels of the Lafayette formation or the water-bearing sands of the underlying Eocene deposits; in the lowlands the alluvial sands and gravels of Pleistocene and Recent age form the source. The waters are generally soft, but according to the statements of well owners some are moderately hard and some are ferruginous. Detailed information concerning wells at or in the vicinity of Lorado, Marmaduke, and Paragould is given in the table on page 190.

The sands and gravels which largely compose the alluvial deposits below the surface clays in the lowlands west and east of Crowleys Ridge contain water in large quantities; these beds may be tapped by wells from 10 to 175 feet deep. The Eocene strata which underlie Crowleys Ridge and which are present beneath the alluvial deposits of the lowlands, and the Cretaceous strata which underlie the Eocene deposits, contain important water-bearing beds; these may be tapped at depths of 100 feet and over in Crowleys Ridge, and at depths of 200 feet and over in the lowlands. The lower limit of possible water-bearing beds found in the Eocene and Cretaceous deposits is the Paleozoic basement rocks, which lie at an estimated maximum depth of 1,200 feet or more in the extreme east. The waters of the Eocene and Cretaceous deposits are under hydrostatic pressure, which in the Mississippi lowland may be sufficient to produce flows.

Small springs are numerous in Crowleys Ridge and are utilized to some extent for domestic and farm supplies. As reported by the owners, some of the spring waters are soft, some are hard, and some are ferruginous; a few are rendered turbid by suspended particles of clay.

LOCAL SUPPLIES.

Paragould.—The municipal water supply of Paragould (population 5,248, census of 1910) is obtained from two wells. Detailed information concerning the system has been furnished by A. P. Mack, mayor, and L. Stedman, superintendent of waterworks. The wells are 512 feet deep and 6 inches in diameter (Nos. 7 and 8, p. 190).

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The water is raised by air lift at the rate of 353 gallons a minute from each well. The water is stored in two 120,000-gallon reservoirs at the pump station and is distributed through 5 miles of mains. The maximum direct pressure is 120 pounds per square inch. The daily consumption for all purposes is between 400,000 and 500,000 gallons.

Detailed information concerning wells at Paragould owned by the Crystal Ice Co., the Paragould Brick Co., and the St. Louis, Iron Mountain & Southern Railway Co. is given in the table on page 190.

Rural supplies.—Several typical wells used for domestic and farm supplies are described in the table on page 190. Logs or incomplete logs of several such wells are as follows:

Incomplete log of well of S. P. Weigart, 5½ miles north of Marmaduke.

[No. 6, p. 190.]

Eocene (Wilcox formation):	Feet.
White sand	26
Sand, water bearing	50
Coarse white sand, water bearing	85
Red sand with some red clay, 8 inches thick	93
Sand, water bearing; water red when first pumped but clears on continued pumping. After standing or boiling, water becomes red	98
Layer of "pipe" clay 1 inch thick	98
Not reported to	102

Log of well of R. A. Dortch, 12 miles northwest of Marmaduke, in the NE. ¼ sec. 8, T. 19 N., R. 6 E.

	Thickness.	Depth.
	Feet.	*Feet.*
Soil	1	1
Red clay	2	3
Sand	2	5
Blue clay	14	19
Sand, water bearing	20	39

Log of well of Joe Canfee, of Lafe, 3½ miles north of Beech Grove, in the SE ¼ NE. ¼ sec. 11, T. 18 N., R. 4 E.

	Thickness.	Depth.
Quaternary (alluvium):	*Feet.*	*Feet.*
Loam	3.5	3.5
Clay	4	7.5
Fine sand, water bearing	7.5	15
Blue mud	12	27
Sand and gravel, water bearing	3	30

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Wells in Greene County.

	Location.				Owner.	Driller.	Authority.	Date completed.	Approximate elevation above sea level.	Depth.	Diameter.	Depth to principal water-bearing bed.	Depth to other water-bearing beds.	Geologic name of water-bearing formation.
	Place.	T.	R.	Sec.										
									Feet.	*Feet.*	*Inches.*	*Feet.*	*Feet.*	
1	Lorado, 1½ miles southwest of.	16 N.	3 E.	35.....	W. C. Nutt.....	Allen Daniels.....	J. M. Rhea....	1904	.....	80	8	60–80	.....	Wilcox (?) formation.
2	Lorado, 3 miles southeast of.	.....	.....	.....	D. M. Powers....	.....	Owner.....	1905	.....	122	6	.....	.....	Do.
3	Marmaduke, 9 miles northwest of.	.....	.....	.....	W. Y. Smith.....	.....	.....do.....	1911	.....	57	10	50–57	.....	Do.
4	Marmaduke, 10 miles northwest of.	.....	.....	.....	J. A. Smith.....	Tobe Hamilton...	.....do.....	1909	(a)	55	10	50–55	.....	Do.
5	Marmaduke, 2½ miles north of.	18 N.	6 E.	1, N. ½, SW. ¼.	Arch McBride, Rector.	H. Johnson, Rector.	.....do.....	1908	290±	70	4	60–70	.....	Do.
6	Marmaduke, 5½ miles north of.	19 N.	7 E.	30 W. ½, NE. ¼.	S. P. Weigart, Rector.	W. D. Cudd, Rector.	.....do.....	1911	.....	102	2	50–98	.....	Do.
7	Paragould.....	.....	.....	.....	Town.....	Thos. Fleming, Pine Bluff.	L. Stedman...	1910	276±	512	6	472	135	Wilcox formation.
8	.....do.....	.....	.....	.....	.....do.....	.....do.....	.....do.....	1910	276±	512	6	472	135	Do.
9	.....do.....	.....	.....	.....	Paragould Brick Co.	.....	.....	.....	276±	120	.....	120	60	Wilcox (?) formation.
10	.....do.....	.....	.....	.....	Crystal Ice Co.....	.....	.....	.....	276±	120	6	.....	.....	Do.
11	.....do.....	.....	.....	.....	.....do.....	.....	.....	.....	276±	120	6	.....	.....	Do.
12	.....do.....	.....	.....	.....	.....do.....	.....	.....	.....	276±	120	6	.....	.....	Do.
13	.....do.....	.....	.....	.....	St. Louis, Iron Mountain & Southern Ry. Co.	.....	J. R. Stephens, chief engineer.	.....	276	180	10	.....	.....	Do.

[a] Elevation about 55 feet above low-water level of Cache River.

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	Location.				Character of principal water-bearing bed.	Level of water below surface.	Yield per minute.	Method of lift.	Cost of well.	Cost of machinery.	Use.	Quality of water.	Remarks.
	Place.	T.	R.	Sec.									
						Feet.	*Gallons.*						
1	Lorado, 1½ miles southwest of.	16 N.	3 E.	35.....	Yellow sand.....	65	.....	.....	$25	.....	Domestic.....	Soft.....	
2	Lorado, 3 miles southeast of.	.....	.....	.....	Sand.....	109	.....	.....	.....	.....	.....do.....	.....	Bored type.
3	Marmaduke, 9 miles northwest of.	.....	.....	.....	.....	.....	.....	.....	15	.....	.....do.....	Soft.....	Do.
4	Marmaduke, 10 miles northwest of.	.....	.....	.....	Sand.....	40	.....	Hand.	16	.....	.....do.....	.....do.....	Do.
5	Marmaduke, 2½ miles north of.	18 N.	6 E.	1, N. ½, SW. ¼.	Sand and gravel...	50	.....	.....	30	.....	.....do.....	Alkaline.....	
6	Marmaduke, 5½ miles north of.	19 N.	7 E.	30, W. ½ NE. ¼.	Sand.....	50	.....	Hand.	65	.....	.....do.....	Soft, ferruginous.	
7	Paragould.....	.....	.....	.....	Coarse sand.....	32	353	Air....	4,000	.....	Municipal supply.	Soft and sulphurous.	Combined yield of 2 wells used for municipal supply.
8	.....do.....	.....	.....	.....	.....do.....	32	353	..do...		.....	.....do.....	.....do.....	
9	.....do.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	Boilers and mud-mixing.	.....	Yields an abundant supply.
10	.....do.....	.....	.....	.....	.....	20	200	.....	.....	.....	Manufacture of ice.	.....	
11	.....do.....	.....	.....	.....	.....	20		.....	.....	.....	.....do.....	.....	
12	.....do.....	.....	.....	.....	.....	20		.....	.....	.....	.....do.....	.....	
13	.....do.....	.....	.....	.....	.....	.....	50	.....	.....	.....	Boilers.....	.....	

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INDEPENDENCE COUNTY.

PHYSIOGRAPHY.

Independence County is in the northeast-central part of the State, west of Jackson County, and is on the border between the Coastal Plain and the Ozark province. The area is 762 square miles and the population, according to the census of 1910, is 24,776.

The greater part of the county is included within the Ozark province, a rugged, deeply dissected plateau which, within the county limits, lies 500 to 1,150 feet above sea level. This plateau is crossed from northwest to southeast by White River, which flows through a narrow gorge 200 to 500 feet deep.

The remainder of the county, embracing a strip 3 to 6 miles wide bordering the county on the east and an area a few miles wide extending up the valley of White River as far as Batesville, is included in the Mississippi embayment, which is a part of the Gulf Coastal Plain. The greater part of the Coastal Plain portion lies 240 to 250 feet above sea level and is a part of the subdivision known as the Advance lowland; a smaller part is a narrow, more or less clearly defined terrace bordering the Ozark province 40 to 100 feet or more above the bottom lands of Black River; this is the northern extension of the Grandglaise terrace of Lonoke County (p. 23). White River flows out from the Ozark province into the Advance lowland a little south of the center of the county. Black River forms the eastern boundary of the county from the northeastern corner southward to Jacksonport, where it joins White River.

Only that part of the county included in the Coastal Plain is treated in this report; here lumbering and agriculture are the chief industries.

GEOLOGY.

The Ozark province is underlain by Paleozoic limestones, cherts, shales, and sandstones of Ordovician, Mississippian, and Pennsylvanian age. The contact between these rocks and the unconsolidated sedimentary materials composing the Coastal Plain is marked by an abrupt erosion escarpment. Along the line of this escarpment the upper eroded surface of the older rocks passes to the eastward at a steep angle beneath the younger materials.

The oldest post-Paleozoic strata outcropping in the area are glauconitic sands interbedded with laminated clays and subordinate lenses of shell marl of Upper Cretaceous age and are probably referable to the Nacatoch sand; these form the body of the Grandglaise terrace in the vicinity of Newark and northward probably to and beyond the county line. Limestones of Eocene age belonging to the Midway

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formation appear in the Grandglaise terrace along the margin of the Ozark province in the extreme southeast. Undifferentiated Eocene and Cretaceous strata underlie the remainder of the lowland area beneath an estimated thickness of 100 to 150 feet of alluvial deposits. Little is known about these buried deposits, but they are believed to consist chiefly of sands, clays, and perhaps limestones, the thickness probably not exceeding 200 or 300 feet within the county. They rest upon the eastward-sloping surface of the buried Paleozoic rocks, the depth to which probably does not exceed 400 feet.

On the hills along the eastern margin of the Ozark province and on the Grandglaise terrace are scattered deposits of gravel, which probably represent the Lafayette formation (Pliocene?).

The alluvial deposits which cover the Eocene and Cretaceous consist of sands, clays, loams, and gravels. In the flood plains of the streams the alluvial materials immediately underlying the surface to an undetermined depth are of Recent age; in the level interstream areas they are of Pleistocene age. The Pleistocene alluvial deposits are irregularly bedded, but in general grade downward from light-colored, compact, silty clays at the surface through fine sands to coarse, water-bearing sands and gravels at the base, the total thickness, though undetermined, probably not exceeding 150 feet. They rest upon strata of Eocene age.

WATER RESOURCES.

GENERAL CONDITIONS.

The statements which follow apply only to the small area in the east included in the Advance lowland. Here the domestic water supplies are obtained chiefly from wells 10 to 100 feet deep. Except in the narrow terrace along the western margin of the lowland, where only moderate amounts of water are obtained from strata of Eocene and Cretaceous age, the wells tap the abundantly water-bearing sands and gravels of the alluvial deposits, the waters of which are soft to moderately hard. The undifferentiated Eocene and Cretaceous deposits which underlie the alluvial deposits also contain water-bearing beds which may be tapped by wells 150 to 400 feet deep. Flowing wells probably can not be obtained within the county.

LOCAL SUPPLIES.

The town of Newark (population 595, census of 1910) is on the Grandglaise terrace bordering the Ozark province along the western margin of the lowland. Shale of Paleozoic age lies 30 to 40 feet beneath the surface. The beds overlying the shale consist in de-

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WATER RESOURCES.

GENERAL CONDITIONS.

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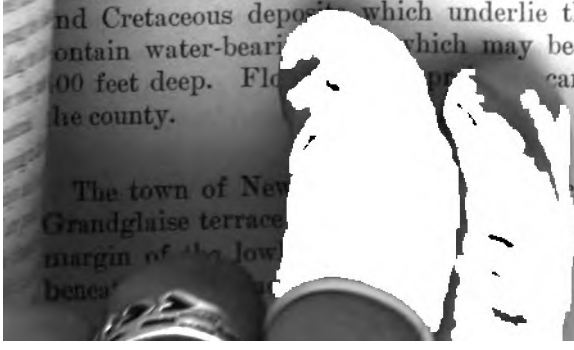

The town of New[illegible] ensus of 1910) is on the Grandglaise terrace[illegible] ovince along the western margin of the low[illegible] ic age lies 30 to 40 feet benea[illegible] the shale consist in de-

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scending order of light brown, yellow, and red loam and clay, gray marl containing shells and shark teeth, and coarse basal water-bearing sands and gravels which are the main source of domestic water supplies. The fossiliferous marls probably belong to the Nacatoch sand of the Upper Cretaceous.

The log of one well has been furnished by J. W. Sisk as follows:

Log of well at Newark, Independence County.

	Thickness.	Depth.
	Feet.	*Feet.*
[Pleistocene?]:		
Yellow loam (loess?)	8	8
Black loam or clay (loess?)	8	16
[Upper Cretaceous (Nacatoch sand?)]:		
Yellow sand	1	17
Black mud	1	18
Gray, soft limestone or marl containing mollusks and shark teeth	2	20
Sand	1	21
Black mud containing wood and leaves	½	21½

JACKSON COUNTY.

PHYSIOGRAPHY.

Jackson County comprises 632 square miles in the northeast-central part of the State, between Independence County on the west and Poinsett County on the east. Its population at the time of the census of 1910 was 23,501. Agriculture is the chief industry and includes the raising of cereals, fruits, and hay. Two cotton compresses, an oil mill, and several sawmills and mills which manufacture wood products are located at Newport. Lumbering is also an important industry.

A relatively small area in the southwestern part of the county is included in the Ozark province, a rugged, broken area lying 400 to 600 feet above sea level. The remainder of the county is included in the Advance lowland and Grandglaise terrace of the Mississippi embayment which is a part of the Gulf Coastal Plain. The Grandglaise terrace is a narrow ridge or dissected terrace bordering the Ozark province just west of the St. Louis, Iron Mountain & Southern Railway, the crest of which is approximately 300 feet above sea level. The Advance lowland is a plain lying 200 to 260 feet above sea level and sloping slightly to the southward. In the interstream areas the surface is gently undulating and partly timbered and the soil and subsoil are loam or silty clay. The broad flood plains of the streams are a few feet lower than the interstream areas, are in part swampy, and are traversed by numerous bayous. Between the swamps and bayous are fertile heavily timbered ridges of sand or

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sandy loam, some rising a few feet higher than the general level of the lowland.

Black River forms the western boundary from the northwestern corner of the county to Jacksonport, where it joins White River—a stream which flows in a general southerly direction from Jacksonport to the southern boundary of the county. Cache River enters the county on the east and flows a little west of south to the southern boundary.

GEOLOGY.

In the Ozark province in the southwestern part of the county the surface is immediately underlain by Paleozoic rocks of Pennsylvanian age. Along their eastern border the Paleozoic rocks are separated from the materials of the Coastal Plain by an abrupt erosion escarpment along which their eroded surface passes beneath the deposits of the Coastal Plain and extends to the eastward to increasing depths, forming the basement upon which the latter rest; these basement rocks were encountered in a well at Newport at a depth of 655 feet. (See section, p. 197.)

Pebbly fossiliferous limestones interbedded with gray to yellowish sands belonging to the Midway formation (Eocene) outcrop in the basal 20 or 25 feet of the east-facing escarpment of the Grandglaise terrace. The Midway is overlain by reddish, pebbly sands, probably of the same age as the similar sands (Lafayette formation) overlying the Eocene strata of Crowleys Ridge; the red sands are overlain by dark and light, more or less sandy loams resembling certain facies of the loess of Crowleys Ridge and probably of the same age (middle Pleistocene). Scattered patches of gravel on the Paleozoic hills west of the Grandglaise terrace probably also represent the Lafayette formation. The Midway formation is separated from the alluvial deposits of the Advance lowland to the east by an abrupt erosion escarpment. Eocene and Cretaceous strata are believed to underlie the Advance lowland beneath 100 to 150 feet of alluvial deposits of Quaternary age; they probably consist mainly of sands and clays, in part water-bearing, and rest upon the Paleozoic basement rocks. At Newport the basement rocks were struck in a well at a depth of 655 feet and their upper surface probably inclines to greater depths to the eastward.

The alluvial deposits which immediately underlie the Advance lowland to estimated depths of 100 to 150 feet consist of loams, clays, sands, and gravels of Pleistocene and Recent age. The Pleistocene deposits, which outcrop in the nearly level interstream areas, are irregularly bedded, but in general grade downward from fine compact loams or silty clays at the surface through fine sands to coarse water-

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bearing sands and gravels at the base. Paralleling the streams are numerous ridges of sand and sandy loam which rise above high-water level of the present streams and are probably of Pleistocene age. The flood plains of the streams are underlain to undetermined depths by Recent alluvial sands, clays, and loams.

WATER RESOURCES.

GENERAL CONDITIONS.

Wells 10 to 100 feet deep furnish the principal domestic water supplies in the Advance lowland, which includes the greater part of the county. The wells tap the abundantly water-bearing sands and gravels of the alluvial deposits, the water standing within 10 to 30 feet of the surface. As reported by the well owners some of the well waters are soft, some are hard, and some are ferruginous; with perhaps a few exceptions they are potable and are suitable for domestic and industrial purposes. The undifferentiated Tertiary and Cretaceous strata which underlie the alluvial deposits contain water-bearing beds and constitute an important undeveloped source of artesian water. Flowing wells probably can not be obtained in the Advance lowland in this county. Small springs are numerous in the Grandglaise terrace and in the Ozark province in the southwestern part of the county.

LOCAL SUPPLIES.

The waterworks plant of Newport (population 3,557, census of 1910) is owned by the Newport Water, Light & Power Co., concerning which information has been furnished by S. Blackburn. Water from White River is filtered by means of a Roberts pressure filter having a daily capacity of 500,000 gallons and is distributed to the consumers from a standpipe having a capacity of 70,000 gallons. The direct pressure is about 45 pounds per square inch, and the maximum pressure from the pumps for fire protection is 135 pounds per square inch. The total length of the distributing mains is 6 miles, and the daily consumption is approximately 30,000 gallons for domestic use and 50,000 gallons for manufacturing.

The Newport Ice Co. owns a well 100 feet deep and 6 inches in diameter, completed in 1898. Mr. R. J. Hugully, the informant, states that a 6-inch casing extends to a depth of 85 feet, and the water, which comes from gravel penetrated in the bottom of the well, stands within 12 feet of the surface. The water is soft and is used for the manufacture of ice. The cost of the well and a pump operated by steam was $500.

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In 1900 (?) an oil-prospecting well was drilled 1 mile southwest of Newport (sec. 10, T. 11 N., R. 3 W.) to a depth of 1,000 feet. The following log has been published by Purdue:[1]

Log of oil-prospecting well 1 mile southwest of Newport.

	Thickness.	Depth.
	Feet.	*Feet.*
Clay and sand	30	30
Sand	75	105
"Soapstone"	50	155
Quicksand	500	655
Rock of different kinds, ending in flint	345	1,000

Purdue says:

The 105 feet of clay and sand at the top are of Recent [and Pleistocene] age; the rocks from the base of the quicksand downward are supposedly Paleozoic. The 550 feet between the Recent and the Paleozoic may all be Cretaceous, though it is possible that the upper 50 feet, reported as "soapstone," is Tertiary.

JEFFERSON COUNTY.

PHYSIOGRAPHY.

Jefferson County comprises 903 square miles in the southeast-central part of the State, west of Arkansas County. Its population at the time of the census of 1910 was 52,734. Only that part of the county lying north and east of Arkansas River is in the area covered by this report. The chief industry is agriculture and the leading crop is cotton, although cereals are grown to an important extent. The rice-growing industry has been introduced in recent years, and in certain places in the northeast is rapidly growing in importance.

The county is included within two well-defined topographic divisions of the Gulf Coastal Plain. In the west an area varying in width from 3 miles in the north to 16 miles in the south forms part of an upland which is extensively developed in the interstream areas of southwestern Arkansas; within this county the upland lies 300 to 350 feet above sea level. The remainder of the county is included within the Advance lowland, the general surface of which is a plain 190 to 235 feet above sea level sloping slightly to the south. Arkansas River traverses the lowland from northwest to southeast and forms the southwestern boundary of the area here treated. Nearly all the land northeast of the river is included within the gently undulating flood plain of Arkansas River, is in part swampy, and is traversed by numerous bayous and abandoned stream channels. The soil is fertile and, except where cleared for cultivation, is heavily timbered;

[1] Purdue, A. H., U. S. Geol. Survey Water-Supply Paper 145, pp. 96, 97, 1905.

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the areas above high-water level and the areas protected from overflow by levees produce large crops, particularly of cotton.

GEOLOGY.

Strata of Eocene age, referable chiefly to the Jackson formation, outcrop in the upland area in the western part of the county; undifferentiated Eocene deposits underlie the remainder of the county beneath 125 feet or more of Quaternary alluvium. Although nothing definite is known concerning the Eocene deposits beneath the alluvium, they are believed to consist of 500 feet or more of sands, clays, and marls, in part water bearing. The Eocene deposits are probably underlain by similar deposits of Cretaceous age, which doubtless also contain water-bearing beds. The Cretaceous strata are believed to rest on a deeply buried basement of Paleozoic rocks. The alluvial deposits in the Advance lowland northeast of Arkansas River have an estimated thickness of 125 to 150 feet and consist of alluvial loams, clays, sands, and gravels. The surface materials are probably for the most part of Recent age, but some of the higher interstream areas may be of Pleistocene age. The thickness of the Recent deposits has not been determined, but it is probable that Pleistocene deposits underlie them and intervene between them and the Eocene deposits. The sands and gravels of the alluvial deposits are abundantly water bearing.

WATER RESOURCES.

Domestic supplies.—In the area northeast of Arkansas River water for domestic use is obtained chiefly from wells 15 to 125 feet deep, which tap the abundantly water-bearing sands and gravels of the alluvial deposits; the waters stand in the wells 5 to 20 feet below the surface. According to the reports received from well owners, most of the waters are hard, but some are soft, and a few are ferruginous. The undifferentiated Eocene and Cretaceous deposits which intervene between the alluvial deposits and the deeply buried Paleozoic basement rocks also contain important water-bearing beds, the waters of which are under sufficient hydrostatic pressure to bring them nearly to the surface, and in wells 1,000 feet or more deep perhaps above the surface. At Lake Dick wells have been drilled as deep as 350 feet and at Langford as deep as 274 feet.

In the part of the county southwest of Arkansas River wells 50 to 100 feet in depth are common, and the deep wells listed in the table on page 200 (Nos. 4–11) have been drilled at and near Pine Bluff and at Redfield.

Wells for irrigation.—Wells for irrigating rice lands have been drilled in the vicinity of McGrew, New Gascony, and Wabbaseka,

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detailed information concerning seven of which is given on page 200. The wells are 35 to 125 feet deep and yield 390 to 2,000 gallons of water a minute. The cost of sinking the wells and erecting pumping plants ranges from $450 to $1,550 per well, the average cost of production based on five wells being $600 for each 1,000 gallons of yield per minute, or at the rate of 60 cents for each gallon of yield a minute. Incomplete analyses of samples of water from two irrigation wells near Wabbaseka are given in the table opposite page 302 (Nos. 23 and 24).

The following is the log of an irrigation well owned by John Ingram, sr., 5 miles east of Wabbaseka (No. 15, p. 200):

Log of well of John Ingram, sr., 5 miles east of Wabbaseka.

	Thickness.	Depth.
Quaternary alluvium:	*Feet.*	*Feet.*
Not reported	19	19
Argillaceous sand and gravel, water bearing	16	35
Sand	8	43
Red sand grading into white sand below, bearing a dark-colored water	8	51
Coarse sand, water bearing	8	59
Gravel, water bearing	2	61
Sand, water bearing	5	66

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Wells in Jefferson County.

	Location.				Owner.	Driller.	Authority.	Date completed.	Approximate elevation above sea level.	Depth.	Diameter.	Depth to principal water-bearing bed.	Geologic name of water-bearing formation.
	Place.	T.	R.	Sec.									
									Feet.	*Feet.*	*Inches*	*Feet.*	
1	McGrew (near)	4 S.	7 W.		John Ingram, sr.		J. S. Jones	1910		35	4	25–35	Quaternary alluvium.
2	New Gascony, 2 miles northwest of.	5 S.	7 W.	31, NE. ¼	John M. Gracie	Layne & Bowler, Stuttgart.	Owner	1910		125	24	35–125	Do.
3	do	5 S.	7 W.	31, NE. ¼	do	United Well Co., Stuttgart.	do	1911		125	24	35–125	Do.
4	Pine Bluff				S. Geirreiter		J. J. Martin[a]			300			
5	do				St. Louis Southwestern Ry.		J. S. Berry[a]	1897	216	840	5½	840	Wilcox formation.
6	do				do	W. B. S. Sharpe & Bro.	R. M. Galbraith.[a]	1898	216	890	8		Do.
7	do				Pine Bluff Water & Light Co.	do	F. G. Bridges[a]	1898		915	6	864–915	Do.
8	do				Sawyer-Austin Lumber Co.	W. B. Sharpe	Owner[a]	1899		915	8		Do.
9	do				Pine Bluff Ice Co.		Jeff Hicks[a]			300	10	26–100	Quaternary.
10	do				Arkansas Cotton Oil Co.	Johnson & Fleming, Memphis, Tenn.	Owner[a]	1904	215	826	4	806–826	
10a	Pine Bluff, 7 miles southeast of.	6 S.	8 W.	33, NE. ¼ NW. ¼.	B. L. Rutherford	T. Fleming	Owner	1908	200±	167	13	125–167	Quaternary alluvium.
11	Redfield				St. Louis, Iron Mount. & Southern Ry.	C. H. Winters	C. H. Winters[a]			545	6	404–412	Wilcox formation.
12	Wabbaseka, 1 mile northeast of.				W. L. Davis	George Hestand, Pine Bluff.	Owner	1910	198±	95	25		Quaternary alluvium.
13	Wabbaseka, 1½ miles southeast of.	4 S.	7 W.	21	Shelby Bros.	Owners	G. A. Shelby	1910	198±	90	9⅝	65–90	Do.
14	Wabbaseka, three-fourths mile north of.	4 S.	7 W.	7	N. T. Roberts, Pine Bluff, Ark.	A. D. Bunn	Owner	1911	198±	97	10		Do.
15	Wabbaseka, 5 miles east of.	4 S.	7 W.	13, NW. ¼	John Ingram, sr.	John Ingram & Bros.	Hezekiah Ingram.		200±	66	4	61–66	Do.

[a] Veatch, A. C., Geology and underground water resources of northern Louisiana and southern Arkansas: U. S. Geol. Survey Prof. Paper 46, pp. 174–175, 1906.

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	Location.				Character of principal water-bearing bed.	Level of water below surface.	Yield per minute.	Method of lift.	Cost of well.	Cost of machinery.	Use.	Quality of water.	Remarks.
	Place.	T.	R.	Sec.									
						Feet.	*Galls.*						
1	McGrew (near)	4 S.	7 W.				2,000				Irrigation	Soft	
2	New Gascony, 2 miles northwest of.	5 S.	7 W.	31, NE. ¼	Sand and gravel	17	2,000	Steam	$750	$800	do	Hard and sulphurous.	
3	do	5 S.	7 W.	31, NE. ¼	do	17	2,000	do	750	800	do	do	
4	Pine Bluff												
5	do					20						Soft	
6	do					22	650					do	Length of strainer, 60 feet.
7	do					31							Yield of this and another similar well, 600 gallons per minute. In 1902 the static head had decreased to −46 feet.
8	do					47						Soft	Forms a soft red scale.
9	do					26						Hard, ferruginous.	
10	do					28	30+					Soft	
10a	Pine Bluff, 7 miles southeast of.	6 S.	8 W.	33, NE. ¼ NW. ¼	Sand and gravel	4	4,000	Steam	3,000		Irrigation		
11	Redfield					60	20						
12	Wabbaseka, 1 mile northeast of.				Sand	15		Steam	1,000	800	Irrigation	Soft and ferruginous.	
13	Wabbaseka, 1½ miles southeast of.	4 S.	7 W.	21	Coarse sand and gravel.	7	1,500	do	300	150	do		Analysis 23, p. 302.
14	Wabbaseka, three-fourths mile north of.	4 S.	7 W.	7	Sand and gravel	15	2,000	do	1,000		do	Alkaline	
15	Wabbaseka, 5 miles east of.	4 S.	7 W.	13, NW. ¼	White sand	8	390	do	41	85	Domestic and irrigation.		Analysis 24, p. 302.

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LAWRENCE COUNTY.

PHYSIOGRAPHY.

Lawrence County lies west of Green and Craighead counties, on the border between the Ozark province and the Gulf Coastal Plain. Its area is 592 square miles, and its population was given by the census of 1910 as 20,001. The western part of the county, embracing a little less than half of the total area, forms a part of the Ozark province, a rugged, dissected area 400 feet or more above sea level; the remainder of the county is included in the Mississippi embayment, which is a part of the Gulf Coastal Plain, and only this part is here considered. In this section agriculture is the chief industry, and includes the raising of cotton, the common cereals, rice, hay, and vegetables.

Along the western margin of the Coastal Plain, in the southern part of the county, is a narrow terrace lying 330 or 340 feet above sea level and 70 to 100 feet above the level of the lowland to the east, which is the northward extension of the Grandglaise terrace of Independence and Jackson counties.

The remainder of the county to the east is included in the Advance lowland, a nearly level or gently rolling plain lying 260 to 280 feet above sea level and sloping slightly to the south. The interstream areas of this lowland are white clay flats, poorly drained and partly wooded. The flood plains bordering the streams are 3 to 6 miles wide and present networks of bayous, abandoned channels, and swamps, separated by higher, rolling, partly forested tracts of sand and sandy loam. Black River flows across the Advance lowland from north of Black Rock a little west of south to the southern boundary, where it is joined by Strawberry River, which flows in from the northwest. Cache River forms the eastern boundary.

GEOLOGY.

The Ozark province in the western part of the county is underlain by Paleozoic rocks of Mississippian and pre-Carboniferous age; the contact between these rocks and the deposits of the Gulf Coastal Plain is a steep, eastward-facing erosion escarpment against which the younger deposits rest; the older rocks extend eastward beneath the younger deposits, reaching greater depths in that direction; they form the basement upon which the deposits of the Coastal Plain rest.

The Grandglaise terrace, which extends from Independence County a short distance into Lawrence County, is composed chiefly of stratified sands and clays probably belonging to the Nacatoch sand of the Upper Cretaceous. These beds, however, are capped by 3 to 10 feet

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of pebbly sands and loams, probably corresponding in part to the Lafayette formation (Pliocene?) and in part to the loess of Crowleys Ridge. On the crest of the hills immediately west of the Grandglaise area are scattered patches of gravel deposits, probably also representing the Lafayette formation.

Beneath 150 to 180 feet of alluvial deposits the Advance lowland is underlain in descending order by undifferentiated strata of Eocene and Cretaceous age, which at an undetermined depth rest on a basement of Paleozoic rocks; the Eocene and Cretaceous deposits contain water-bearing beds. The alluvial deposits which immediately underlie the Advance lowland consist of loams, clays, sands, and gravels of Pleistocene and Recent age. The Pleistocene deposits which outcrop in the interstream areas, though irregularly bedded, in general grade downward from light-gray silty clays or loams at the surface through fine sands to coarse, water-bearing sands and gravels at the base. At many places, however, low ridges of sand or sandy loam rise above the level of the white clay flats and are probably of Pleistocene age. The flood plains of the streams are underlain to an undetermined depth by Recent alluvial sands, clays, and loams, which probably rest upon the Pleistocene alluvium.

WATER RESOURCES.

GENERAL CONDITIONS.

In the Advance lowland water for domestic and industrial purposes is obtained chiefly from wells, 15 to 100 feet deep, which tap the abundantly water-bearing sands and gravels of the alluvial deposits, though a few wells have been sunk to greater depths. According to the reports of well owners many of the waters are moderately hard, but some are soft and a few are ferruginous. The waters stand in the wells within 5 to 20 feet of the surface.

The strata beneath the alluvial deposits, which (in descending order) are believed to be of Eocene and Cretaceous age and which rest upon a basement of Paleozoic rocks, probably contain important water-bearing beds that would be tapped by wells ranging in depth from 200 feet to an estimated maximum depth of 600 or 700 feet. The upper surface of the basement Paleozoic rocks lies at its greatest depth in the extreme eastern part of the county. Flowing wells probably can not be obtained from the deposits of the Coastal Plain within the limits of the county.

A few small springs issuing from the Eocene deposits which outcrop along the western border of the Advance lowland are used to a small extent for domestic supplies.

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LOCAL SUPPLIES.

Walnut Ridge.—At Walnut Ridge (population 1,798, census of 1910) water for domestic and industrial uses is obtained chiefly from wells 30 to 100 feet deep. The general character of the strata underlying the town and the surrounding country may be understood by referring to the logs of two wells used for irrigation (p. 205).

Alicia.—At Alicia (population 168, census of 1910) the St. Louis, Iron Mountain & Southern Railway obtains water for the boiler supply of locomotives from a well 77 feet deep (No. 1, p. 206), a log of which is given as follows:

Log of well of the St. Louis, Iron Mountain & Southern Railway at Alicia.

	Thickness.	Depth.
Pleistocene alluvium:	Feet.	Feet.
Tough clay	8	8
Yellow quicksand	55	63
Sand and gravel, water bearing	14	77

Black Rock.—Black Rock (population 1,078, census of 1910) is on the border between the Ozark province and the Gulf Coastal Plain. Many of the wells in the vicinity pass through a thin covering of deposits of the Coastal Plain and enter the underlying Paleozoic rocks, but some obtain water from sands and gravels at the base of the deposits of the Coastal Plain. A well of the latter kind is owned by Clay Sloan, who has furnished the following log:

Log of well of Clay Sloan, 1 mile west of Black Rock.

	Thickness.	Depth.
	Feet.	Feet.
Clay	52	52
Argillaceous sand and gravel	3	55

Lynn.—Lynn is also on the border between the Ozark province and the Gulf Coastal Plain; the Paleozoic rocks are overlain by 20 to 50 feet of clays, sands, and gravels of post-Paleozoic age; many of the wells tap the sands and gravels which are water bearing. The log of a well owned by O. F. Rider, which entered the Paleozoic rocks at a depth of 46 feet, is as follows:

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Log of well of O. F. Rider, 1 mile west of Lynn.

	Thickness.	Depth.
Tertiary:	*Feet.*	*Feet.*
Unconsolidated materials, character not reported	46	46
Paleozoic:		
Limestone	277	323

Wells for irrigation.—In the Advance lowland the soil, topography, and water supply afford favorable conditions for the rapid growth of the rice-growing industry, and water for irrigating rice lands is obtained from wells tapping the water-bearing sands and gravels of the alluvial deposits and yielding 800 to 2,500 gallons a minute. Detailed information concerning two irrigation wells near Walnut Ridge is given in the table on page 206 (Nos. 6 and 7), and the logs are as follows:

Log of well of S. C. Dowell, 1 mile northeast of Walnut Ridge.

	Thickness.	Depth.
Soil and Pleistocene alluvium:	*Feet.*	*Feet.*
Gray gumbo soil	6	6
Clay	15	21
Fine sand	15	36
Clay	10	46
Coarse sand and fine gravel	19	65
Coarse gravel, water bearing	112	177

Log of well of Robinson & Cornett, 1½ miles southeast of Walnut Ridge.

	Thickness.	Depth.
Pleistocene alluvium:	*Feet.*	*Feet.*
Clay	3	3
Hardpan	11	14
Sand, quicksand, and fine gravel	51	65
Coarse gravel, water bearing	16.5	81.5

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Wells in Lawrence County.

	Location.				Owner.	Driller.	Authority.	Date completed.	Approximate elevation above sea level.	Depth.	Diameter.	Depth to principal water-bearing bed.	Depth to other water-bearing beds.	Geologic name of water-bearing formation.
	Place.	T.	R.	Sec.										
									Feet.	*Feet.*	*Inches*	*Feet.*	*Feet.*	
1	Alicia				St. Louis, Iron Mountain & Southern Ry. Co.		J. R. Stephens, chief engineer.	1902	250±	77	6	63–77		Pleistocene alluvium.
2	Black Rock				C. H. Martin	Chas. Smith and Geo. Shale.	Owner	1906	265±	80	6	70		Paleozoic (?) rocks.
3	Black Rock, 1 mile west of.				Clay Sloan	Geo. Henderson	do	1901		55	6	67–70		Lafayette (?) formation.
4	Hoxie				St. Louis, Iron Mountain & Southern Ry. Co.		J. R. Stephens, chief engineer.		274	65	10			Pleistocene alluvium.
5	Lynn, 1¼ miles west of	16 N.	3 W.	23, SE. ¼	O. F. Rider	Worth Drilling Co., Worth.	Owner	1910		323	5	319		Paleozoic rocks.
6	Walnut Ridge, 1 mile northeast of.	17 N.	1 E.	25, SE. ¼	S. C. Dowell	Layne & Bowler, Stuttgart.	do	1910	277	177	11¼	65–177		Pleistocene alluvium.
7	Walnut Ridge, 1½ miles southeast of.	16 N.	1 E.	1, NE. ¼	Robinson & Cornett.	J. E. Brown and A. D. Cornett.	A. D. Cornett.	1911	276±	81½	9⅝	65–81½		Do.

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	Location.				Character of principal water-bearing bed.	Level of water below surface.	Yield per minute.	Method of lift.	Cost of well.	Cost of machinery.	Use.	Quality of water.	Remarks.
	Place.	T.	R.	Sec.		*Feet.*	*Galls.*						
1	Alicia				Sand and gravel	15					Boilers		13.5 feet of 5½-inch No. 6 Cook strainer in lower part of well. Well yields 1,500,000 gallons per month. Analysis 25, p. 302.
2	Black Rock				Limestone	70		Wind.	$250		Domestic	Hard	Entered rock at a depth of 12 or 15 feet.
3	Black Rock, 1 mile west of.				Gravel	20		Hand.	75		do	do	
4	Hoxie										Boilers		Well yields 7,000,000 gallons per month. Analysis 26, p. 302.
5	Lynn, 1½ miles west of.	16 N.	3 W.	23, SE. ¼	Limestone	80			350		Domestic	Hard	Entered rock at a depth of 46 feet.
6	Walnut Ridge, 1 mile northeast of.	17 N.	1 E.	25, SE. ¼	Coarse gravel	12	2,500	Steam.	2,700		Irrigation		65 feet of 24-inch steel pit; 22 feet of 11¼-inch casing, and 90 feet of 11¼-inch strainer. Analysis 27, p. 302.
7	Walnut Ridge, 1½ miles southeast of.	16 N.	1 E.	1, NE. ¼	Gravel	14	800	Gas.	400	510	do	Hard	

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LEE COUNTY.

PHYSIOGRAPHY.

Lee County, in the eastern part of the State adjacent to the northwestern part of the State of Mississippi, has an area of 601 square miles and a population, according to the census of 1910, of 24,252. Agriculture, which includes the raising of cotton, cereals, and in lesser quantities potatoes, tobacco, and sorghum, is one of the principal industries; rice growing has been introduced in the county and in the area west of Crowleys Ridge will probably become important. Lumbering is another important industry. At Marianna, the county seat, there are several large lumber mills, a spoke factory, a brick-making plant, and a large cottonseed-oil mill.

The county is in the Mississippi embayment of the Gulf Coastal Plain and is topographically subdivisible into three parts, as follows: Crowleys Ridge, the Advance lowland, and the Mississippi lowland.

Crowleys Ridge, which trends north and south a little east of the center of the county, is interrupted by a gap 6 to 8 miles wide through which L'Anguille River flows from northwest to southeast. Only the southern nose of the part of the ridge north of the gap appears in this county. The part of the ridge south of the gap is a hilly, partly wooded area, 3 to 5 miles wide, extending from the southern boundary northward to Marianna, a distance of 6 miles; the maximum elevation of the ridge has not been exactly determined, but is probably between 325 and 375 feet above sea level, or 125 to 150 feet above the lowlands to the east and west; the eastward-facing slope of the ridge is steeper than the westward-facing slope, though both are sharply defined. The Advance lowland, which includes the part of the county west of Crowleys Ridge, is in general a plain 200 to 230 feet above sea level. The interstream areas are gently undulating, being in part wooded and in part open, grass-covered prairies. The broad, slightly depressed flood plains of the streams are heavily timbered and are interspersed with swamps, shallow lakes, and bayous. The Mississippi lowland includes the part of the county east of Crowleys Ridge, a poorly drained, heavily timbered plain lying 200 to 220 feet above sea level; swamps, bayous, and abandoned stream channels are numerous.

Mississippi River forms the eastern boundary of the county; St. Francis River flows from north to south, east of Crowleys Ridge, and joins the Mississippi just south of the southern boundary in Phillips County. L'Anguille River enters the county west of Crowleys Ridge, flows from northwest to southeast through a gap in the ridge and joins St. Francis River. The western part of the county is drained by Big Creek, a tributary of White River.

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GEOLOGY.

Crowleys Ridge, to a height of 50 to 80 feet or more above its base, is composed of irregularly bedded sands and clays, in part lignitic, belonging to the Jackson formation of the Eocene. Eocene deposits representing the Jackson formation, and in descending order several formations older than the Jackson, underlie Crowleys Ridge to an estimated depth of 1,200 feet or more; they are underlain by deposits of Cretaceous age, which at an estimated depth of 3,000 feet or more rest upon a basement of rocks believed to be of Paleozoic age. The Eocene and Cretaceous deposits underlie the remainder of the county beneath 125 to 200 feet of alluvial deposits and contain important water-bearing beds. In Crowleys Ridge the Eocene strata are overlain unconformably by 10 feet or more of coarse sands and gravels belonging to the Lafayette formation (Pliocene?), above which are 50 to 100 feet of calcareous loess forming the capping material of the ridge. In places the loess contains numerous fossil remains of land shells.

The Advance lowland west of Crowleys Ridge is underlain to a depth of 125 to 200 feet by loams, clays, sands, and gravels of Pleistocene and Recent age. The Pleistocene deposits rest unconformably upon Eocene strata throughout the area, and outcrop in the interstream areas; although irregularly bedded, in general they grade downward from silty clays, loams, or fine sands at the surface through fine sands to coarse, water-bearing sands and gravels at the base. In the flood plains of the streams the Pleistocene deposits are overlain by an undetermined thickness of alluvial loams, clays, sands, and gravel. The Mississippi lowland east of Crowleys Ridge is underlain to an estimated depth of 150 to 225 feet by Quaternary alluvial loams, clays, sands, and gravels. Here the surface materials are probably of Recent age, but Pleistocene alluvium may intervene between the Recent and the underlying Eocene deposits. The coarser phases of the alluvium contain water in great quantities.

WATER RESOURCES.

GENERAL CONDITIONS.

Domestic water supplies are obtained chiefly from wells 25 to 150 feet deep. In the lowlands they tap the abundantly water-bearing sands and gravels of the Quaternary alluvium, the waters of which stand in the wells 10 to 50 feet below the surface. In Crowleys Ridge the source is either the sands and gravels of the Lafayette formation (Pliocene?) or the sands of the underlying Jackson formation (Eocene) the waters of which will rise to within 30 to 140

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feet of the surface, depending upon the depth and the elevation of the mouth of the well. In the lowlands the hydrostatic pressure of the deeply buried Eocene and Cretaceous waters is sufficient to bring them within less than 100 feet of the surface, and in the Mississippi lowland wells 1,000 feet or more in depth will probably flow. As reported by the well owners, some of the well waters are soft, some are hard, and some are ferruginous; in general they are suitable for all ordinary domestic and industrial uses. Small springs are fairly common in Crowleys Ridge, particularly at the foot of the steep, east-facing slopes, and are utilized to a small extent for domestic and farm supplies.

LOCAL SUPPLIES.

Marianna.—Marianna (population 4,810, census of 1910), the county seat, owns a municipal water-supply system, information concerning which has been furnished by the mayor, T. E. Wood. Water is obtained from two 6-inch wells 619 feet deep (Nos. 3 and 4, p. 212); the water rises within 60 feet of the surface and is forced to a small reservoir by means of two air compressors having a combined capacity of 1,000 gallons a minute, whence it is pumped to an elevated tank having a capacity of 70,000 gallons, from which it is distributed through 5 miles of mains. The tank pressure is 60 pounds per square inch and the direct pressure from the pumps for fire protection is 150 pounds per square inch. The daily consumption is 235,000 gallons for domestic use and 15,000 gallons for manufacturing. The water is soft.

A well, 125 feet deep and 3 inches in diameter, is owned by the Marianna Light & Power Co. (No. 5, p. 212), the log of which is as follows:

Log of well of Marianna Light & Power Co., Marianna.

	Thickness.	Depth.
Pleistocene alluvium:	*Feet.*	*Feet.*
Loam	1	1
Clay	3	4
Blue mud	86	90
Blue mud and quicksand	10	100
Clay	10	110
Sand and gravel, water bearing	15	125

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Lagrange.—A well owned by the Kennedy Heading Co., 4 miles east of Lagrange, is 176 feet deep (No. 1, p. 212); the log is as follows:

Log of well of Kennedy Heading Co., 4 miles east of Lagrange.

	Thickness.	Depth.
Pleistocene (?):	*Feet.*	*Feet.*
Red clay (loess?)	40	40
Interbedded layers of blue, brown, and white clay	40	80
Pliocene (?) (Lafayette formation?):		
Sand, gravel, and clay	90	170
Gravel, water bearing	6	176

The following is the log of a 273-foot well about 5 miles east of Lagrange owned by J. O. Hale, of Marianna (well No. 2, p. 212):

Log of well of J. O. Hale, about 5 miles east of Lagrange.

	Thickness.	Depth.
Pleistocene (?):	*Feet.*	*Feet.*
Red clay (loess?)	50	50
Blue clay (loess?)	50	100
Pliocene (?) (Lafayette formation?):		
Sand, gravel, and blue clay, mixed	10	110
Eocene:		
Interbedded blue, white, and brown clays	90	200
Fine sand and clay, mixed, with a layer of hard sand a few inches thick at top	68	268
White sand, water bearing; stopped drilling on hard rock	5	273

Wells for irrigation.—Rice has been successfully grown on the prairies in the western part of the county. Detailed information concerning several wells in the vicinity of Moro, used for irrigating rice lands, is given on pages 212–213 (wells Nos. 7–11). The wells range in depth from 145 to 195 feet and yield from 2,000 to 3,500 gallons a minute. The water is obtained from the Pleistocene alluvial sands and gravels underlying the Advance lowland. The log of S. D. Johnston's irrigation well is as follows:

Log of well of S. D. Johnston, 2¾ miles northwest of Moro.

(No. 10, p. 212.)

	Thickness.	Depth.
Pleistocene alluvium:	*Feet.*	*Fee*
Hard clay or "hardpan"	15	15
Very fine sand gradually increasing in coarseness to coarse gravel, water bearing; stopped drilling on clay	180	195

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Wells in Lee County.

	Location.				Owner.	Driller.	Authority.	Date completed.	Approximate elevation above sea level.	Depth.	Diameter.	Depth to principal water-bearing bed.	Depth to other water-bearing beds.	Geologic name of water-bearing formation.
	Place.	T.	R.	Sec.										
									Feet.	*Feet.*	*Inches*	*Feet.*	*Feet.*	
1	Lagrange, 4 miles east of	1 N.	4 E.	28?.....	Kennedy Heading Co.	E. C. Guerrant, Marianna.	O.C. Norment, Marianna.	.....	.....	176	2½	170	.....	Eocene (?) deposits.
2	Lagrange, 5 miles east of	1 N.	4 E.	23.....	J. O. Hale, Marianna.	.....do.....	.....do.....	1912	.....	273	2	268	.....	Eocene deposits.
3	Marianna (well No. 1)..	.....	.....	.....	Town.....	.....do.....	T. E. Wood...	.....	236±	619	6	.....	.....	Do.
4	Marianna (well No. 2)..	.....	.....	.....	.....do.....	.....do.....	.....do.....	.....	236±	619	6	.....	.....	Do.
5	Marianna, one-half mile south of post office.	.....	.....	.....	Marianna Light & Power Co.	.....do.....	Owners.....	1909	236	125	3	125	30–100	Pleistocene alluvium.
6	Marianna, 3 blocks from post office.	.....	.....	.....	Marianna Ice & Storage Co.	.....do.....	.....do.....	1908	236±	116	6	110	.....	Do.
7	Moro.....	3 N.	1 E.	33, SE. ¼..	Johnston Stock Co., Marianna.	Layne & Bowler, Stuttgart.	A. W. Bonner.	1909	.....	165	10	.....	.....	Do.
8	Moro, 2 miles northwest of.	3 N.	1 E.	33, SW. ¼..	.....do.....	.....do.....	.....do.....	1911	.....	145	16	.....	.....	Do.
9	Moro, 2 miles north of..	2 N.	1 E.	4, NW. ¼..	.....do.....	.....do.....	S. D. Johnston	1909	.....	145	13	129–145	.....	Do.
10	Moro, 2¾ miles northwest of.	3 N.	1 E.	32, SW. ¼..	S. D. Johnston, Marianna.	.....do.....	Owner.....	1911	.....	195	13	178–195	.....	Do.
11	Moro, 7½ miles northwest of.	3 N.	1 W.	10.....	C. E. Rimmer, Wheetley.	Arkansas Well Co., Brinkley.	.....do.....	1910	200±	148	12	125–148	.....	Do.

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	Location.				Character of principal water-bearing bed.	Level of water below surface.	Yield per minute.	Method of lift.	Cost of well.	Cost of machinery.	Use.	Quality.	Remarks.
	Place.	T.	R.	Sec.									
						Feet.	*Galls.*						
1	Lagrange, 4 miles east of.	1 N.	4 E.	28?.....	Gravel.....	125	.....	Steam.	.....	.....	Boilers.....	.....	170 feet of 2½-inch casing.
2	Lagrange, 5 miles east of.	1 N.	4 E.	23.....	White sand.....	140	.....	Gas...	.....	.....	Domestic.....	.....	265 feet of 2-inch casing, followed by 8 feet of strainer.
3	Marianna (well No. 1)	.....	.....	.....	.....do.....	60	400	Air...	.....	.....	Municipal supply.	.....	Combined yield is used for municipal supply; total daily consumption, 250,000 gallons. Analysis 28, p. 302.
4	Marianna (well No. 2)	.....	.....	.....	.....do.....	60	600	...do...	.....	.....	.....do.....	.....	
5	Marianna, one-half mile south of post office.	.....	.....	.....	Gravel.....	30	.....	Steam.	$200		Boilers.....	Soft with magnesium carbonate.	
6	Marianna, 3 blocks from post office.	.....	.....	.....	.....	50?	35	.....	600		Manufacture of ice.	Ferruginous...	
7	Moro.....	3 N.	1 E.	33, SE. ¼..	Sand and gravel...	26	2,000	Steam.	1,750	750	Irrigation.....	Hard.....	
8	Moro, 2 miles northwest of.	3 N.	1 E.	33, SW. ¼..	.....do.....	26	3,000	...do...	1,750	750	.....do.....	.....do.....	
9	Moro, 2 miles north of	2 N.	1 E.	4, NW. ¼..	.....do.....	26	3,500	...do...	2,300		.....do.....	.....	24-inch steel pit to depth of 65 feet, followed by 13-inch casing, then 40 feet or more of 13-inch strainer to bottom of well. Analysis 29, p. 302.
10	Moro, 2¼ miles northwest of.	3 N.	1 E.	32, SW. ¼..	.....do.....	26	3,500	...do...	2,300		.....do.....	.....	24-inch steel pit to depth of 65 feet, followed by 13-inch casing, then by 40 feet or more of 13-inch strainer to bottom of well. Analysis 30, p. 302.
11	Moro, 7½ miles northwest of.	3 N.	1 W.	10.....	Gravel.....	32	800	.....	1,400	764	.....do.....	Hard.....	Pit 60 feet deep and 30 inches in diameter, and 88 feet of 12-inch casing and strainer.

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LONOKE COUNTY.

PHYSIOGRAPHY.

Lonoke County, in the east-central part of the State, comprises an area of 794 square miles and has a population (census of 1910) of 27,983. Agriculture, lumbering, and stock raising are the chief industries. The first commercial crop of rice produced in the State was raised near Lonoke, the county seat, in 1904, since which time the industry has rapidly grown.

A few square miles in the northwestern part of the county, included in the Ozark province, is hilly, the tops of the hills and ridges lying 400 to 600 feet above sea level. The remainder of the county is included in the Gulf Coastal Plain, which is here separable into Chinquapin Ridge and the Advance lowland.

Chinquapin Ridge, or the "sandhills" lying just east of the Ozark province and east of Austin and Cabot, is a sandy ridge having a maximum width of several miles, a north-south extent of approximately 12 miles, and an elevation of 375 or 400 feet above sea level. The Advance lowland is a nearly level or gently rolling plain, 200 to 250 feet above sea level, and sloping slightly to the south. The interstream areas present numerous tracts of open, grass-covered prairies, separated by slightly lower timbered lands. Grand Prairie, an irregular but in general continuous tract of prairie, lies northeast of Bayou Two Prairie and extends from a point 6 miles northwest of Lonoke southeastward through Lonoke, Prairie, and Arkansas counties (p. 27); Prairie Longue, a similar prairie, extends southeastward through Lonoke County south of Bayou Two Prairie, and parallel to Grand Prairie (p. 27). The broad flood plains of the streams, for the most part swampy and heavily timbered, are characterized by numerous ponds, abandoned stream channels, and bayous. The southwestern part of the county falls within the flood plain of Arkansas River and supports a vigorous growth of timber.

The county is drained chiefly by Cypress Bayou, Wattensas Bayou, Bayou Two Prairie, Bayou Meto, and Indian Bayou.

GEOLOGY.

Paleozoic rocks of Pennsylvanian age outcrop in the Ozark province in the northwest and are present beneath deposits of the Coastal Plain throughout the remainder of the county. The Paleozoic rocks are separated from the deposits of the Coastal Plain by a relatively steep southeastward-facing erosion escarpment along the line of which the eroded surface of the Paleozoic rocks passes under the deposits of the Coastal Plain and extends to the eastward beneath them, reaching greater depths in that direction.

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Strata of Cretaceous age, dipping slightly to the southeast, rest upon the Paleozoic basement rocks, but so far as known do not outcrop in this county; the Upper Cretaceous fossils *Exogyra costata* Say and *Cardium eufaulense* Conrad have been recognized in a calcareous sandstone taken from a depth of 15 or 20 feet in a well at Cabot (p. 40). The Cretaceous deposits are overlain by southeastward-dipping strata of Eocene age; limestones of the Midway formation have been observed in outcrops near Cabot (p. 49), and probably the beds composing Chinquapin Ridge east of Austin and Cabot belong to the Eocene.

Throughout the Advance lowland the Eocene deposits are overlain and concealed by 125 to 200 feet of Quaternary alluvial loams, clays, sands, and gravels of Pleistocene and Recent age. The Pleistocene alluvium, which rests upon the Eocene strata and outcrops in the interstream areas, though irregularly bedded grades downward in general from gray compact silty clays at the surface through fine sands to coarse water-bearing sands and gravels at the base. The Recent alluvium immediately underlies the flood plains of the present streams.

WATER RESOURCES.

GENERAL CONDITIONS.

Ordinary supplies.—In the Advance lowland water for domestic, industrial, and irrigation uses is obtained chiefly from wells 15 to 180 feet deep, tapping the abundantly water-bearing sands and gravels of the Quaternary alluvial deposits, the waters of which stand in the wells 10 to 50 feet below the surface. As reported by the well owners, some of the waters are soft, some are hard, and some are ferruginous; with an occasional exception, they are suitable for all ordinary uses. The undifferentiated Eocene and Cretaceous deposits, which in the southeastern part of the county probably reach a thickness of 1,000 feet or more, contain important water-bearing beds, the waters of which are probably under sufficient hydrostatic pressure to bring them within less than 100 feet of the surface, but not sufficient to cause overflows at the surface. Cisterns are in use at some places along the western border of the Gulf Coastal Plain, and particularly at Cabot.

Irrigation.—The rice-growing industry in Arkansas had its beginning in this county (pp. 144–149). From the first water for irrigating the rice lands has been obtained from wells, and because of the great quantities of water obtainable from the sands and gravels of the Quaternary deposits at depths of 25 to 180 feet wells have continued to be used. The water stands in the wells at depths of 10 to 50 feet and is lifted by means of powerful machinery, the yield per minute ranging from 600 to 4,000 gallons for each well. The cost of drill-

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ing and equipping the wells ranges from $580 to $5,000, the difference in cost depending chiefly on the depth and diameter of the wells and on the capacity of the pumping machinery. The average cost, based on 15 wells, is about $811 for each 1,000 gallons of yield per minute, or at the rate of 81 cents for each gallon of yield per minute. Detailed information concerning 21 irrigation wells is given in the table on pages 220–223.

LOCAL SUPPLIES.

Lonoke.—Lonoke (population 1,547, census of 1910), the county seat, is equipped with a municipal water-supply system, owned by W. Y. Bransford, information concerning which has been furnished by the owner and by the postmaster. Water is obtained from two wells, one of which is 103 feet deep and the other 105 feet deep (Nos. 23, 24, p. 222). The water is distributed from a tank having a capacity of 18,000 gallons, and the daily consumption is about 36,000 gallons; the water is ferruginous.

A log of the 105-foot well, the figures in which are approximations, is as follows:

Log of 105-foot well at waterworks plant, Lonoke.

	Thickness.	Depth.
Pleistocene alluvium:	*Feet.*	*Feet.*
Yellowish clay	27	27
Reddish clay, rather hard	3	30
Sand and gravel	18	48
Reddish, sticky clay	28	76
Thin layers of blue clay	4	80
Sand and gravel, water bearing	25	105

Holland.—At Holland station, 4 miles southwest of Cabot, the St. Louis, Iron Mountain & Southern Railway Co. drilled in 1911 a 1,352-foot well, the log of which is as follows:

Log of well owned by the St. Louis, Iron Mountain & Southern Railway Co., Holland.

[No. 16, p. 220.]

	Thickness.	Depth.
Quaternary or Tertiary:	*Feet.*	*Feet.*
Surface material, character not stated	36	36
Paleozoic:		
Black shale	799	835
Dark-gray sand	57	892
Light shale	11	903
Black sand	14	917
Shale and hard shells	6	923
Hard black sand	14	937
Brown shale	78	1,015
Brown sand	80	1,095
Black shale	80	1,175
Black sand	50	1,225
Light shale	127	1,352

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A 12½-inch casing was used to a depth of 141 feet and a 10-inch casing to a depth of 365 feet. As no water was obtained, the casings were withdrawn and the well abandoned.

Cabot.—Branner[1] has published the two following logs of wells at and near Cabot:

Log of well at Neeley & Neeley's ginhouse, Cabot.

[No. 2, p. 220.]

	Thickness.	Depth.
	Feet.	*Feet.*
Red and sandy clays	39	39
Calcareous clay (Cretaceous) [or Midway (Eocene)]	1	40
Marl (Cretaceous)	6	46
Carboniferous shale to the bottom of the well	70	116

Log of well in NE. ¼ SW. ¼ sec. 25, T. 4 N., R. 10 W.

	Thickness.	Depth.
	Feet.	*Feet.*
Soil	2	2
Red clay	10	12
Sandy clay	16	28
Calcareous clay (Cretaceous) [or Midway (Eocene)]	1	29
Marl (Cretaceous); stopped on Carboniferous shale	8	37

The log of another well, of interest chiefly because of the geologic information it affords, is as follows:

Log of well, known as the Nursery well, owned by J. P. Murrel, Cabot.

	Thickness.	Depth.
	Feet.	*Feet.*
Not reported	15	15
Gray calcareous clay	5	20
Black clay and gray calcareous sandstone, with shells; contained iron-stained gravel at depth not stated; stopped digging on hard blue rock (Paleozoic)	26	46

Materials collected between the depths of 20 and 46 feet in this well consist in part of dark-gray calcareous clay, with numerous fragments of shells, some of which are arranged in seams and pockets, and in part of gray calcareous fossiliferous sandstone, with fragments of lignite. Both the clay and sandstone contain Upper Cretaceous fossils, probably belonging to the Nacatoch sand. (See p. 40.)

[1] Branner, J. C., The clays of Arkansas: U. S. Geol. Survey Bull. 351, p. 133, 1908.

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Wells for irrigation.—Wells for irrigating rice lands have been drilled at many places on the prairies, particularly in the vicinity of Carlisle, Lonoke, England, Cobb, and Scott. Detailed information concerning 21 of them is given in the table on pages 220–223. The following are logs of irrigation wells:

Log of well of W. H. Fuller, 4½ miles southwest of Carlisle.

[No. 3, p. 220.]

	Thickness.	Depth.
Pleistocene alluvium:	*Feet.*	*Feet.*
In descending order, hard clay, yellow clay, red clay, and white clay	25	25
Quicksand and gravel	40	65
Gravel and small bowlders	75	140

Log of well of Mr. Hubbard, 1½ miles east of Carlisle.

[No. 6, p. 220.]

	Thickness.	Depth.
Pleistocene alluvium:	*Feet.*	*Feet.*
Red clay	19	19
Fine sand and thin strata of clay	19	38
Quicksand	40	78
Fine and coarse sand containing logs of wood	62	140
Gravel and bowlders, water bearing; stopped on blue clay, probably of Eocene age	40	180

Log of well of Robert Medendorp, 1½ miles north of Carlisle.

[No. 5, p. 220.]

	Thickness.	Depth.
Soil and Pleistocene alluvium:	*Feet.*	*Feet.*
Soil	1	1
Yellow subsoil	2	3
Clay	12	15
Fine yellow sand	85	100
Blue clay	5	105
Mixed clay	15	120
Coarse sand, water bearing	5	125
Gravel	21	146
Gravel and bowlders	4	150
Blue clay	1	151
Sand, gravel, and bowlders	5	156
Blue clay	2	158

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Log of well of J. H. Sims, 3 miles southwest of Carlisle.

[No. 8, p. 220.]

	Thickness.	Depth.
Pleistocene alluvium:	*Feet.*	*Feet.*
Sandy loam	2	2
Hard red clay	18	20
Sand	10	30
Sand and fine gravel	40	70
Gravel, water bearing	20	90
Coarse gravel, water bearing; stopped on clay	41	131

Log of well of B. F. Fromholz, 4 miles southeast of Lonoke.

[No. 21, p. 220.]

	Thickness.	Depth.
Pleistocene alluvium:	*Feet.*	*Feet.*
Clay	33	33
Quicksand	10	43
Clay	10	53
Quicksand and gravel	40	93
Gravel, water bearing	37	130
Clay, containing a mixture of gravel and bowlders	70	200
Eocene:		
Hard sand	40	240
Sand and clay	60	300

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Wells in Lonoke County.

	Location.				Owner.	Driller.	Authority.	Date completed.	Approximate elevation above sea level.	Depth.	Diameter.	Depth to principal water-bearing bed.	Depth to other water-bearing beds.	Geologic name of water-bearing formation.
	Place.	T.	R.	Sec.										
									Feet.	*Feet.*	*Inches*	*Feet.*	*Feet.*	
1	Cabot				O. H. Beasley		Owner		260±	100?	48			Nacatoch sand?
2	Cabot (at ginhouse)				Neeley and Neeley		J. C. Branner[a]		275±	116				
3	Carlisle, 4½ miles southwest of.	1 N.	7 W.	8, W. ½ of NW. ¼.	W. H. Fuller, Lonoke.	Owner	Owner			140	9⅝	25–140		Pleistocene alluvium.
4	Carlisle (near)	2 N.	7 W.	9	W. N. Hilbert	S. Jordon	do	1910		161	9⅝	60–161		Do.
5	Carlisle, 1½ miles north of.	2 N.	7 W.	10, SW. ¼	Robert Medendorp	F. A. Raprich, Lonoke.	do	1907		158	9⅝	125–158		Do.
6	Carlisle, 1½ miles east of.	2 N.	7 W.		Mr. Hubbard	Joe Peters, Brinkley.	E. G. Norton, Brinkley.			180				Do.
7	Carlisle, 3 miles east of.	2 N.	7 W.	24, NE. ¼	C. E. Smiley	Mark Brown	Owner	1911		165	13			Do.
8	Carlisle, 3 miles southwest of.	2 N.	7 W.	32	J. H. Sims	Elmer Morris	do	1911		131	10	70–131	50	Do.
9	Carlisle, 3 miles north of.	3 N.	7 W.	34, W. ½ of SW. ¼.	W. J. D. Alexander.	Mr. Bitzler	do			168	8½			Do.
10	Carlisle, 6 miles southwest of.	1 N.	7 W.	6, NW. ¼	Elmer Morris	Owner	do	1910		152	10	80–152		Do.
11	Carlisle, 6½ miles west of south of.	1 N.	7 W.	19	Wm. Zimmerman, Burnside, Ill.	Fuller & Morris	J. R. Moery	1905		155	10	90–155		Do.
12	England, 1 mile west of.				Morris & Gray	Layne & Bowler, Stuttgart.	G. W. Morris	1909	228±	165	11	60–165		Do.
13	England, one-half mile northwest of.	2 S.	9 W.		Arkansas Cotton Oil Co.	Corless Well Co., Memphis, Tenn.	R. J. Lanford	1902	228±	110	6			Do.
14	England, 600 yards northwest of post office.	2 S.	9 W.	10	do	Cook Well Co., St. Louis, Mo.	do	1902	227±	80	5			Do.
15	England, one-half mile southeast of.				R. J. Lanford	J. H. Massey	Owner	1911	231±	70	1½	50–70	20,35	Do.
16	Holland				St. Louis, Iron Mountain & Southern Ry.		J. R. Stephens, chief engineer.	1911	250±	1,352	10			Do.

[a] Branner, J. C., The clays of Arkansas: U. S. Geol. Survey Bull. 351, p. 133, 1908.

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	Location.				Character of principal water-bearing bed.	Level of water below surface.	Yield per minute.	Method of lift.	Cost of well.	Cost of machinery.	Use.	Quality of water.	Remarks.
	Place.	T.	R.	Sec.		*Feet.*	*Galls.*						
1	Cabot										Domestic	Hard	Dug type, curbed with brick. Used by railroad employees.
2	Cabot (at ginhouse)												Encountered Carboniferous shale at depth of 46 feet.
3	Carlisle, 4½ miles southwest of.	1 N.	7 W.	8, W. ½ of NW. ¼.	Sand and gravel	25	2,000	Steam.	$560	$160	Domestic and irrigation.	Soft	
4	Carlisle (near)	2 N.	7 W.	9		45		do			Irrigation		50 feet of pit and 110 feet of 9⅝-inch casing and strainer.
5	Carlisle, 1½ miles north of.	2 N.	7 W.	10, SW. ¼	Sand and gravel	44	2,500	do	1,000		do		Pit 50 feet deep and 6 feet square. Analysis 31, p. 302.
6	Carlisle, 1½ miles east of.	2 N.	7 W.		do						do		
7	Carlisle, 3 miles east of.	2 N.	7 W.	24, NE. ¼		45	1,700	Steam.	2,200		do	Sulphurous	
8	Carlisle, 3 miles southwest of.	2 N.	7 W.	32	Gravel	31		do	520	190	do	Hard	
9	Carlisle, 3 miles north of.	3 N.	7 W.	34, W. ½ of SW. ¼.	do	28	750	do	550	125	Domestic and irrigation.	Soft	
10	Carlisle, 6 miles southwest of.	1 N.	7 W.	6, NW. ¼	Sand and gravel	27	1,500	do	600	125	do		
11	Carlisle, 6½ miles west of south of.	1 N.	7 W.	19	Gravel	30	2,100	do	620	175	Irrigation	Soft	
12	England, 1 mile west of.					10	2,500	do	2,300		do	Ferruginous	
13	England, one-half mile northwest of.	2 S.	9 W.		Sand and gravel			do			do	do	
14	England, 600 yards northwest of post office.	2 S.	9 W.	10				do			Boilers		Analysis 32, p. 302.
15	England, one-half mile southeast of.							Hand.	35	3	Domestic		Driven type; 1¼-inch casing extends to depth of 70 feet. Analysis 33, p. 302.
16	Holland												No water obtained and well abandoned; rocks of Paleozoic age were penetrated from a depth of 36 feet to the bottom of the well.

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Wells in Lonoke County—Continued.

	Location.				Owner.	Driller.	Authority.	Date completed.	Approximate elevation above sea level.	Depth.	Diameter.	Depth to principal water-bearing bed.	Depth to other water-bearing beds.	Geologic name of water-bearing formation.
	Place.	T.	R.	Sec.										
								Feet.	*Feet.*	*Inches*	*Feet.*	*Feet.*		
17	Jebb, 1½ miles northeast of.	2 S.	8 W.	4.....	J. E. Biscoe.....	Layne & Bowler, Stuttgart.	Owner.....	1910	.....	120	24	.....	.....	
18	Lonoke, 1½ miles southwest of.	.....	.....	.....	W. E. & J. N. Wheat.	W. H. Fuller.....	W. E. Wheat..	.....	.....	154	9⅝	.....	.....	Pleistocene alluvium.
19	Lonoke, 1½ miles west of	2 N.	9 W.	24, NW. ¼.	W. P. Fletcher....	.....	Owner.....	1904	240±	120	8	65–120	24	Do.
20	Lonoke, 3 miles north of	.....	.....	.....	Rowena Rice Co..	W. B. Johnson, Memphis, Tenn.	Duff Green....	1909	.....	160	11¾	90–160	.....	Do.
21	Lonoke, 4 miles southeast of.	2 N.	8 W.	33, SW. ¼..	B. F. Fromholz...	F. A. Raprich, Lonoke.	Owner.....	1906	.....	300	9⅝	100–130	.....	Do.
22	Lonoke, 6 miles southeast of.	1 N.	8 W.	11, NE. ¼..	W. H. Hicks.....	United Well Co., Stuttgart.	.....do.....	1912	.....	175	9⅝	75–175	.....	Do.
23	Lonoke.....	.....	.....	.....	W. Y. Bransford..	.....	.....do.....	1901	.....	103	3	78–103	.....	Do.
24	.....do.....	.....	.....	.....	.....do.....	.....	.....do.....	1902	.....	105	4	80–105	.....	Do.
25	Lonoke, 1½ miles southwest of.	2 N.	9 W.	24, NW. ¼.	W. H. Fuller.....	Owner.....	.....do.....	1908	.....	148	10	26–148	.....	Do.
26	Lonoke, 2½ miles southeast of.	2 N.	8 W.	28, SW. ¼..	.....do.....	.....do.....	.....do.....	1907	.....	152	10	26–152	.....	Do.
27	Scott (Pulaski County), 5 miles east of (in Lonoke County).	1 N.	9 W.	30.....	T. W. Steele.....	John Graham.....	.....do.....	1907	.....	84	10	70–84	23	Do.

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	Location.				Character of principal water-bearing bed.	Level of water below surface.	Yield per minute.	Method of lift.	Cost of well.	Cost of machinery.	Use.	Quality of water.	Remarks.
	Place.	T.	R.	Sec.									
						Feet.	*Galls.*						
17	Jebb, 1½ miles northeast of.	2 S.	8 W.	4.....	.....	10	1,500	Steam.	$2,300		Domestic and irrigation.	Hard.....	
18	Lonoke, 1½ miles southwest of.	.....	.....	.....	Gravel.....	32	1,500	...do...	.....	.....	Irrigation.....	.....do.....	
19	Lonoke, 1½ miles west of.	2 N.	9 W.	24, NW. ¼.	Sand and gravel...	24	1,200	...do...	500	160	Domestic and irrigation.	Soft.....	100 feet of 8-inch casing and 20 feet of 6-inch Cook strainer. Irrigates 100 acres.
20	Lonoke, 3 miles north of.	.....	.....	.....	.....do.....	41	800	.....	1,500	250	Irrigation.....	.....	Analysis 35, p. 302.
21	Lonoke, 4 miles southeast of.	2 N.	8 W.	33, SW. ¼.	Gravel.....	40	700	.....	1,000		.....do.....	Soft.....	
22	Lonoke, 6 miles southeast of.	1 N.	8 W.	11, NE. ¼.	Sand and gravel...	35	2,000	Steam.	2,300		Domestic and irrigation.	.....	24-inch pit to depth of 90 feet. Within the pit is 80 feet of 10-inch casing, followed by 20 feet of 13-inch casing, followed by 75 feet of 13-inch strainer to bottom of well. Analysis 37, p. 302.
23	Lonoke.....	.....	.....	.....	Gravel.....	30	.....	.....	.....	.....	Municipal supply.	Ferruginous...	The combined yield of these wells furnishes the municipal water supply; the daily consumption is 36,000 gallons.
24	.....do.....	.....	.....	.....	.....do.....	30	.....	.....	.....	.....	.....do.....	.....do.....	
25	Lonoke, 1½ miles southwest of.	2 N.	9 W.	24, NW. ¼.	Sand and gravel...	26	2,000	Steam.	572	125	Domestic and irrigation.	.....	Analysis 34, p. 302.
26	Lonoke, 2½ miles southeast of.	2 N.	8 W.	28, SW. ¼.	.....do.....	26	2,000	...do...	608	125	.....do.....	Soft.....	
27	Scott (Pulaski County), 5 miles east of (in Lonoke County).	1 N.	9 W.	30.....	Fine gravel.....	12	600	.....	.....	.....	Irrigation.....	Hard.....	Abandoned.

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MISSISSIPPI COUNTY.

PHYSIOGRAPHY.

Lying between Craighead and Poinsett counties on the west, Tennessee on the east, and Missouri on the north, Mississippi County comprises an area of 792 square miles; Mississippi River forms its eastern boundary. At the time of the census of 1910 the population of the county was 30,468. Agriculture and lumbering are the chief industries. The soil is very fertile and produces large crops of cotton, corn, and hay. Except where cleared for cultivation, the surface is heavily timbered, and much lumber is produced.

The county is entirely within the Mississippi lowland. The surface is a nearly level or gently rolling alluvial plain lying 235 to 260 feet above sea level and sloping slightly to the south and west. The highest land in the county, with the exception of Big Lake highlands, a tract of slightly elevated land 2 to 3 miles wide lying west of Big Lake and extending northward into Missouri, is immediately west of the river. Swamps, bayous, and abandoned stream channels are numerous and much of the area is subject to overflow. The greater part of the drainage passes westward into St. Francis River. The western half of the county, with the exception of Big Lake highlands, is included in the area known as the St. Francis Sunk Lands, where the bayous and swamps are separated by low ridges of sandy loam dotted with the so-called "sand blows" of the region. The sand blows are low circular or irregular mounds of clean white sand supposed to have been discharged from underground sources through crevices during the time of the New Madrid earthquake in 1811–12.

GEOLOGY.

The materials underlying the surface of this county to depths estimated at 150 to 225 feet are Quaternary alluvial loams, clays, sands, and gravels. The immediate surface materials are probably all of Recent age, though in some of the higher swells, such as Big Lake highlands west of Big Lake, deposits of Pleistocene age may come to the surface. It is probable that strata of Pleistocene age intervene between the Recent deposits and the underlying older deposits, but this has not been definitely proved. Buried logs are encountered in many wells.

The alluvial deposits are underlain by an estimated thickness of 600 to 1,000 feet of Eocene sands and clays, and the latter are in turn underlain by Cretaceous strata. At an undetermined depth, probably 2,000 feet or more, the Cretaceous deposits rest on a basement of rocks believed to be of Paleozoic age.

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WATER RESOURCES.

GENERAL CONDITIONS.

Water for domestic and industrial supplies is obtained chiefly from wells 10 to 100 feet deep, which tap the abundantly water-bearing sands of the alluvial deposits the waters of which stand in the wells 1 to 30 feet below the surface. According to the reports of well owners, many of the waters are hard and ferruginous, but some are soft.

Both Eocene deposits and the underlying Cretaceous deposits contain important water-bearing beds the waters of which are under sufficient hydrostatic pressure to bring them nearly to or above the surface. Water has been obtained by wells at Blytheville (1,448 feet), Burdette (1,495.5 feet), and at Wilson (1,567 feet), and probably can be obtained anywhere in the county at depths of 1,400 to 2,000 feet.

LOCAL SUPPLIES.

Osceola.—Osceola (population 1,679, census of 1910), the county seat, owns its municipal water plant and obtains water from an 800-foot well (No. 5, p. 228) information concerning which has been furnished by N. B. Baldwin. The water is forced to a standpipe holding 5,000 gallons by a pump having a capacity of 500 gallons a minute. The standpipe pressure is 55 pounds per square inch and the direct pressure from the pump for fire protection is 90 pounds. The daily consumption is between 50,000 and 60,000 gallons.

Blytheville.—T. W. Davis, mayor, states that the town of Blytheville (population 3,849, census of 1910) has drilled a flowing well 1,448 feet deep (No. 1, p. 228) to supply a proposed municipal water plant. The Chicago Mill & Lumber Co. owns a well 520 feet deep 2 miles west of Blytheville (No. 2, p. 228) a partial log of which follows:

Partial log of well of the Chicago Mill & Lumber Co., 2 miles west of Blytheville.

[Authority, W. P. Orr, chief engineer for the company.]

	Thickness.	Depth.
	Feet.	*Feet.*
Soil	20	20
Quicksand	10	30
Not reported	20	50
Fine sand	10	60
Not reported	20	80
Coarse sand yielding hard water	10	90
Not reported	10	100
Fine sand and small pebbles	10	110
Not reported	30	140
Black material resembling lignite	30	170
Not reported	60	230
Fine, gray quicksand	60	290
Not reported	110	400
Fine sandy material	10	410
Not reported	80	490
Coarse white sand becoming coarser in lower 20 feet	30	520

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The materials described to a depth of 140 feet are probably referable to the Quaternary alluvium, and the remainder to the bottom of the well are of Eocene age.

Luxora.—The village of Luxora is equipped with a water-supply system owned by Wood Bros., information concerning which has been furnished by John B. Driver. Water is obtained from Mississippi River and is pumped to a tank having a capacity of 10,000 gallons, from which it is distributed to the consumers through 2 miles of mains. The daily consumption is 10,000 gallons.

Burdette.—A flowing well, owned by the Three States Lumber Co., at Burdette is 1,495 feet deep (No. 4, p. 228). The following is an incomplete log of the well:

Incomplete log of well of the Three States Lumber Co., Burdette.

	Feet.
Sand and gravel at	123
Sand, lignite, and clay	123–1,060
Clay	1,060–1,067
Rock at	1,398
Fine white sand, gravel, and hard clay from the rock to the bottom of the well	1,495.5

The sand and gravel reached at a depth of 123 feet probably represents the basal portion of the Quaternary alluvial deposits. The well probably passed entirely through the Eocene strata which underlie the Quaternary deposits and entered the Cretaceous deposits, although the data are not sufficient to differentiate the beds of the two ages.

Wilson.—A flowing well, owned by Lee Wilson & Co., at Wilson is 1,567 feet deep (No. 7, p. 228). The water is used in boilers at several large sawmills and is the principal domestic supply of the town. No log of the well has been obtained, but according to the informant, Miss June Blackwell, postmistress, rock was struck at a depth of 1,500 feet, and the water, which flows at the surface at the rate of 208 gallons per minute, was obtained from a coarse sand beneath this rock.

Ashport Bend, Mississippi River.—In 1893 four borings were made at Ashport Bend, Mississippi River, Ark., 9 or 10 miles above Osceola, under the auspices of the Mississippi River Commission, the logs of which follow:

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Log of boring No. 1, Ashport Bend, Mississippi River, Ark.

[Elevation of mouth of boring about 32.5 feet above extreme low-water level.]

	Thickness.	Depth.
	Feet.	*Feet.*
Quaternary alluvium:		
Sandy loam	10	10
Blue clay	10	20
Silt	15	35
Fine sand	13	48
Sand and gravel	34	82
Silt	9	91
Very fine sand	9	100
Coarse sand and gravel	36.5	136.5
Eocene (?):		
Fine sand	27.5	164

Log of boring No. 2, Ashport Bend, Mississippi River, Ark.

[Elevation of mouth of boring 30 feet above low-water level.]

	Thickness.	Depth.
	Feet.	*Feet.*
Quaternary alluvium:		
Sandy loam	5	5
Blue clay	15	20
Fine sand	5	25
Blue clay	10	35
Sand and gravel	50	85
Coarse sand	15	100
Fine sand	10	110

Log of boring No. 3, Ashport Bend, Mississippi River, Ark.

[Elevation of mouth of boring 30 feet above low-water level.]

	Thickness.	Depth.
	Feet.	*Feet.*
Quaternary alluvium:		
Sandy loam	5	5
Silt	11	16
Blue clay	38	54
Fine sand	11	65
Sand and gravel	40	105
Fine sand	9	114
Coarse sand	20	134
Coarse sand and gravel	12	146
Eocene (?):		
Fine sand	20	166

Log of boring No. 4, Ashport Bend, Mississippi River, Ark.

[Elevation of mouth of boring 28 feet above low water level.]

	Thickness.	Depth.
	Feet.	*Feet.*
Quaternary alluvium:		
Sandy loam	4	4
Blue clay	38	42
Fine sand	33	75
Coarse sand and gravel	12	87
Blue clay	2	89
Very fine sand	6	95
Coarse sand and gravel	30	125
Fine sand	10	135
Sand and gravel	5	140
Eocene (?):		
Fine sand	28	168

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Wells in Mississippi County.

	Location.				Owner.	Driller.	Authority.	Date completed.	Approximate elevation above sea level.	Depth.	Diameter, inches.	Depth to principal water-bearing bed.	Depth to other water-bearing beds.	Geologic name of water-bearing formation.
	Place.	T.	R.	Sec.										
									Feet.	*Feet.*		*Feet.*	*Feet.*	
1	Blytheville	15 N.	11 E.		Town		T. W. Davis	1911		1,448	8			Cretaceous.
2	Blytheville, about 2 miles west of, near Chickasawba.	15 N.	11 E.	17, NE. ¼	Chicago Mill & Lumber Co.	Johnson & Fleming, Memphis, Tenn.	W. P. Orr	1906	259	520	6	500		Wilcox (?) formation.
3	Boynton	16 N.	8 E.	29, NE. ¼	Mill Shoals Cooperage Co.		P. E. Files	1907	(a)	41	3	24–41		Quaternary alluvium.
4	Burdette, 400 yards south of post office.	14 N.	11 E.	20, SW. ¼	Three States Lumber Co.	Johnson & Fleming, Memphis, Tenn.	Mr. Gilchrist	1910		1,495.5	6	1,420–1,495.5		Cretaceous.
5	Osceola	13 N.	10 E.		Town		N. B. Baldwin		255	800				Cretaceous (?).
6	Osceola (at hotel)				Mr. Beal		A. F. Crider			440+				Wilcox (?) formation.
7	Wilson	11 N.	10 E.		Lee Wilson & Co.	Johnson & Fleming, Memphis, Tenn.	June Blackwell.		245	1,567				Cretaceous.

	Location.				Character of principal water-bearing bed.	Level of water above or below surface.	Yield per minute.	Method of lift.	Use.	Quality of water.	Remarks.
	Place.	T.	R.	Sec.							
						Feet.	*Gallons.*				
1	Blytheville	15 N.	11 E.			+10	300	Flows.			
2	Blytheville, about 2 miles west of, near Chickasawba.	15 N.	11 E.	17, NE. ¼	Sand	−15			Boilers	Ferruginous	
3	Boynton	16 N.	8 E.	29, NE. ¼	do	−12		Steam	do		Driven type; analysis, 38, p. 302.
4	Burdette, 400 yards south of post office.	14 N.	11 E.	20, SW. ¼		+17		Flows.	Domestic and boilers.		1,420 feet 6-inch casing; 54 feet 5-inch cook strainer; and 21.5 feet of pipe at bottom of strainer; analysis 39, p. 302.
5	Osceola	13 N.	10 E.				500		Municipal supply		
6	Osceola (at hotel)								Domestic		Assay 37, p. 304.
7	Wilson	11 N.	10 E.		Coarse white sand	+15(?)	208	Flows.	Domestic and boilers.		

(a) Elevation, 2 feet below the level of the St. Louis, Iron Mountain & Southern Ry. track.

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MONROE COUNTY.

PHYSIOGRAPHY.

Monroe County, in the east-central part of the State, comprises an area of 603 square miles and has a population of 19,907 (census of 1910). Agriculture, lumbering, and stock raising are the chief industries. The agricultural products include cotton, cereals, and vegetables. Rice growing is rapidly becoming important. Wood products are manufactured at several mills at Clarendon, the county seat, and at Brinkley; at the latter place there is also a cottonseed-oil mill.

The county lies within the Advance lowland, one of the topographic divisions of the Gulf Coastal Plain. The surface is, in general, a slightly undulating plain 170 to 210 feet above sea level, sloping slightly to the south. Throughout the greater part of the county east of White River are numerous swamps, bayous, and abandoned stream channels, separated by low, rolling ridges of sand or sandy loam. Much of the surface is poorly drained, and the greater part of the area is wooded; there are a few small tracts of prairie-like land in the northeast. A relatively small area in the west-central part of the county lies west of White River, and about 15 square miles of this section is open, grass-covered prairie, forming a part of Grand Prairie (p. 27). White River enters the county in the northwest and forms the southwestern boundary for a distance of about 18 miles. Cache River flows from north to south in the northwestern part of the county and joins White River at Clarendon.

GEOLOGY.

Throughout the county the materials underlying the surface to estimated depths of 125 to 175 feet are Quaternary alluvial loams, clays, sands, and gravels of Recent and Pleistocene age. The Pleistocene deposits outcrop in the prairies west of White River and probably also in the higher areas east of White River and underlie the remainder of the county beneath Recent deposits. Although irregularly bedded, in general they grade downward from loams or fine, silty clays at the surface, through fine sands to coarse water-bearing sands and gravels at the base. The Recent deposits form the surface materials in the broad, rolling flood plains of White and Cache rivers.

The alluvial deposits rest unconformably on strata of Eocene age, the only definite data concerning which have been furnished by a well at Brinkley, owned by the Farrell Light, Heat & Water Co. Here sands, clays, and gravels, probably referable to the Eocene, were penetrated from a depth of 148 to 565 feet; blue clay containing oyster shells was penetrated between the depths 411 and 415 feet,

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and lignite between the depths 411 and 416 feet. From general considerations it is believed that the Eocene deposits are underlain at some depth, probably not exceeding 1,000 or 1,200 feet, by strata of Cretaceous age, and at an undetermined depth, probably, however, not exceeding 2,500 feet, the Cretaceous deposits are believed to rest on a basement of Paleozoic rocks. Both the Eocene and Cretaceous deposits contain water-bearing beds.

WATER RESOURCES.

GENERAL CONDITIONS.

Domestic water supplies are obtained chiefly from wells 15 to 85 feet deep, tapping the water-bearing sands and gravels of the alluvial deposits, the waters of which stand in the wells at depths of 10 to 30 feet. According to the reports of well owners, some of the waters are hard and some are soft, but with an occasional exception they are suitable for household and farm use. A few wells used for industrial supplies and for irrigation range in depth from 100 to 150 feet, and draw their supplies from the coarse, abundantly water-bearing sands and gravels at the base of the alluvial deposits.

The Eocene strata, which underlie the alluvial deposits, contain important water-bearing beds, as shown by the yield of the 565-foot well at Brinkley (No. 1, p. 232). The Cretaceous deposits, which underlie the Eocene at an undetermined depth, probably contain water-bearing beds. The Eocene and Cretaceous waters are under sufficient hydrostatic pressure to bring them within less than 50 feet of the surface; flowing wells probably can not be obtained except in the low alluvial lands in the southern part of the county, where wells 1,500 feet or more in depth might overflow at the surface.

LOCAL SUPPLIES.

Brinkley.—The municipal water supply of Brinkley (population 1,740, census of 1910) is obtained from a well 565 feet deep (No. 1, p. 232). Information concerning the system has been furnished by Elmo Chaney, manager, through the mayor, R. M. Henderson. The water is forced into a reservoir holding 100,000 gallons by an air compressor having a capacity of 250 gallons a minute. From the reservoir the water is pumped to an elevated tank, holding 60,000 gallons, from which it is distributed through 3 miles of mains. The standpipe pressure is 40 pounds per square inch, though a direct pressure of 100 pounds per square inch can be obtained in case of fire by cutting out the standpipe. The daily consumption for domestic purposes is 70,000 gallons. The water is slightly brackish. The following is a log of the well:

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Log of well of the Farrell Light, Heat & Water Co., Brinkley.

	Thickness.	Depth.
Pleistocene alluvium:	*Feet.*	*Feet.*
Clay	25	25
Sand	123	148
Eocene:		
Clay	2	150
Sand	255	405
Hard blue clay, with oyster shells	6	411
Lignite	4	415
Fine sand and gravel	80	495
Blue clay	2	497
Fine white sand and gravel, water bearing	68	565

Other wells at Brinkley, owned by the Brinkley Ice Co., the Arkansas Cotton Oil Co., and the Brinkley Car Works, are described in the table on page 232.

Wells for irrigation.—Several wells in the vicinity of Brinkley for irrigating rice lands are described in the table on page 232. They range in depth from 140 to 150 feet and tap the coarse water-bearing sands and gravels in the basal portion of the Quaternary alluvium; they yield from 2,000 to 3,500 gallons per minute.

Logs of two irrigation wells are as follows:

Log of well of J. D. Edmunds, near Brinkley.

[No. 5, p. 232.]

	Thickness.	Depth.
Pleistocene alluvium:	*Feet.*	*Feet.*
Hardpan	6	6
Sand	7.75	13.75
Sand and gravel, water bearing	124	137.75
Blue clay	12	149.75

Log of well of H. G. Adams, 1½ miles northwest of Brinkley.

[No. 7, p. 232.]

	Thickness.	Depth.
Soil and Pleistocene alluvium (approximate thickness):	*Feet.*	*Feet.*
Soil and subsoil	13	13
Sand	64	77
Gravel, water bearing	70.5	147.5

Log of well of Harshberger & Staley, 2½ miles southeast of Brinkley, Ark.

[No. 8, p. 232.]

	Thickness.	Depth.
Pleistocene alluvium:	*Feet.*	*Feet.*
Red and yellow clay	20	20
Quicksand	10	30
Sand	10	40
Gumbo and shale	20	60
Sand and gravel, water bearing	82	142

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Wells in Monroe County.

	Location.				Owner.	Driller.	Authority.	Date completed.	Approximate elevation above sea level.	Depth.	Diameter.	Depth to principal water-bearing bed.	Geologic name of water-bearing formation.
	Place.	T.	R.	Sec.									
									Feet.	*Feet.*	*In.*	*Feet.*	
1	Brinkley	3 N.	2 W.		Farrell Light, Heat & Water Co.	Corless Well Co., Memphis, Tenn.	E. G. Norton	1904	208	565		497–565	Eocene.
2	do	3 N.	2 W.		Brinkley Ice Co.	do			±206	114			Pleistocene alluvium.
3	do	3 N.	2 W.		Arkansas Cotton Oil Co.	Cook Well Co., St. Louis, Mo.			±206	100(?)			Do.
4	do	3 N.	2 W.		Brinkley Car Works.	do			±206	98			Do.
5	do	3 N.	2 W.	4, S. ½	J. D. Edmunds	Layne & Bowler, Stuttgart.	E. G. Norton	1910	±189	149.75	9¾	14–138	Do.
6	Brinkley, one-half mile northwest of.	3 N.	2 W.	9, NE. ¼	Donnelly & Federer.	Chas. Golieke, Garden City, Kans.	Frank Federer	1910	190	142	12	112	Do.
7	Brinkley, 1½ miles northwest of.	3 N.	2 W.		H. G. Adams	Layne & Bowler, Stuttgart.	Owner	1910	±200	147.5	13		Do.
8	Brinkley, 2½ miles southeast of.	3 N.	2 W.	25, NE. ¼	Harshberger & Staley, Tippecanoe City, Ohio.	Oscar Lowe, Jennings, La.	H. J. Harshberger	1910		142	11¾	60–142	Do.
9	Palmer, 1 mile northwest of.	1 S.	1 W.	23, SE. ¼	Tim Williams		Owner	1909		70	1½	70	Do.
10	Roe, 1 mile east of (at the Poor Farm).				County	H. H. Rittmann, Stuttgart.	Driller	1904	±200	67	2	60	Do.

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	Location.				Character of principal water-bearing bed.	Level of water below surface.	Yield per minute.	Method of lift.	Cost of well.	Cost of machinery.	Use.	Quality of water.	Remarks.
	Place.	T.	R.	Sec.									
						Feet.	*Gallons.*						
1	Brinkley	3 N.	2 W.		Fine white sand	40		Air			Municipal supply.		Analysis 42, p. 302.
2	do	3 N.	2 W.								Manufacture of ice.		
3	do	3 N.	2 W.								Boilers		
4	do	3 N.	2 W.								do		
5	do	3 N.	2 W.	4, S. ½	Sand and gravel	14		Steam			Irrigation		Analysis 43, p. 302.
6	Brinkley, one-half mile northwest of.	3 N.	2 W.	9, NE. ¼	do	20	3,500	do	$2,200	$1,600.00	do	Alkaline	24-inch pit extends to depth of 60 feet.
7	Brinkley, 1½ miles northwest of.	3 N.	2 W.		do	13	2,000		2,500	750.00	Domestic and irrigation.	Hard	
8	Brinkley, 2½ miles southeast of.	3 N.	2 W.	25, NE. ¼	do	18	1,500	Steam	1,500	900.00	Drinking and irrigation.		Analysis 44, p. 302.
9	Palmer, 1 mile northwest of.	1 S.	1 W.	23, SE. ¼		10		Hand	13		Domestic	Hard	
10	Roe, 1 mile east of (at the Poor Farm).				Gravel	60(?)	7	do	50	5.50	do	do	

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PHILLIPS COUNTY.

PHYSIOGRAPHY.

Phillips County comprises an area of 692 square miles, lying south of Lee County and east of Monroe and Arkansas counties; Mississippi River borders the county on the east. Its population was 33,535 in 1910. Agriculture is the chief industry, but lumbering is also important. The agricultural products include cotton, cereals, and hay. At Helena, the county seat, there are several cotton compresses, cottonseed oil mills, and mills manufacturing wood products.

The three topographic subdivisions of the Mississippi embayment—Crowleys Ridge, the Advance lowland, and the Mississippi lowland—are represented in the county.

Crowleys Ridge includes a small tract of hilly, partly wooded, partly cultivated land in the northeastern part of the county; its maximum elevation is about 400 feet above sea level or about 210 feet above the surrounding lowlands. The east-facing slope is rugged and presents numerous deep, steep-sided gullies; along the western slope the hills are more smoothly rounded and the valleys of the small streams are broader and shallower. The southern terminus of the ridge is about 2 miles southwest of Helena.

The Advance lowland comprises the area lying between Crowleys Ridge and the western boundary of the county and extending southward a maximum of 14 miles from the northern boundary. The surface is a rolling plain 170 to 240 feet above sea level, mostly timbered, with a general slope to the south. The creeks and bayous flow through poorly drained shallow valleys and are separated by low ridges of light to dark loam. One of the more prominent ridges, known as Hickory Ridge, is 20 to 30 feet higher than the surface to the west and extends from a short distance south of Marvel northwestward to the county line. Along the western side of Crowleys Ridge is a well-defined terrace, 1 to 3 miles wide, lying 30 or 40 feet above the lowland immediately to the west, from which it is separated by an abrupt escarpment; it is also separated from Crowleys Ridge on the east by a plainly defined escarpment.

The Mississippi lowland is an area 1 to 12 miles wide, bordering Mississippi River along the entire southeastern side of the county; a few square miles of the area lies east of the southern part of Crowleys Ridge and north of Helena. The lowland slopes from about 200 feet above sea level in the northern part of the county to about 170 feet above sea level in the south. Swamps, lakes, abandoned stream channels, and bayous are numerous, and much of the surface is heavily timbered.

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West of Crowleys Ridge the county is drained by Big Creek, a tributary of White River, and White River forms the boundary of the county for a distance of about 15 miles on the southwest.

GEOLOGY.

The core of Crowleys Ridge to a maximum height of 80 or 90 feet above the level of the Mississippi bottom is composed of Tertiary sands, clays, and gravels referable to the Jackson formation of the Eocene. Undifferentiated deposits of Eocene age underlie the ridge to an estimated depth of 1,200 feet or more and contain important water-bearing beds. The Eocene is underlain by deposits of Cretaceous age, which, at an undetermined depth, probably 3,000 feet or more, are believed to rest on a basement of Paleozoic rocks. The Cretaceous deposits contain water-bearing beds, but their character is not definitely known. Throughout the remainder of the county the Eocene and the subjacent Cretaceous deposits are present beneath Quaternary alluvial deposits estimated to be 120 to 200 feet thick.

In Crowleys Ridge the Eocene sands and clays are overlain unconformably by a known maximum thickness of 80 feet of sands and gravels belonging to the Lafayette formation (Pliocene?), which is in turn overlain by typical loess (Pleistocene), having a maximum measured thickness of approximately 140 feet. The loess caps the ridge, and materials derived from both the Lafayette formation and the loess mantle down over the slopes of the ridge and in most places completely cover the Eocene strata. It is difficult at some places to determine whether these mantling materials are in their original position or have subsequently come to their present position by redeposition or by creep. Fossil land shells are numerous in the loess.

Along the western side of Crowleys Ridge is a terrace 30 to 40 feet above the lowland to the west, the deposits composing which are probably the reworked loess, sands, and gravels of Crowleys Ridge. This terrace is of Pleistocene age, is younger than the loess capping Crowleys Ridge, and older than the alluvium underlying the lowland immediately to the west. The Advance lowland west of Crowleys Ridge is underlain to estimated depths of 125 to 200 feet by Quaternary alluvial loams, clays, sands, and gravels of Pleistocene and Recent age. The Pleistocene alluvium rests on Eocene strata and appears at the surface in the interstream areas. Although irregularly bedded, the materials in general grade downward from fine silts or loams at the surface through fine sands to coarse, water-bearing sands and gravels at the base. Recent stream alluvium immediately underlies the surface in the flood plains of Big Creek and White River. The Mississippi lowland is underlain by alluvial clays and water-bearing sands and gravels to estimated depths of 150 to 200 feet.

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WATER RESOURCES.

GENERAL CONDITIONS.

Water for domestic supplies is derived chiefly from wells 15 to 150 feet deep. In the Advance and Mississippi lowlands the water is obtained from the sands and gravels of the Quaternary alluvium and stands within 10 to 50 feet of the surface. In Crowleys Ridge the wells tap either the water-bearing sands and gravels of the Lafayette formation or the water-bearing sands of the underlying Eocene deposits. Wells on the higher parts of the ridge generally exceed 100 feet in depth and yield waters that rise within 80 to 130 feet of the surface. As reported by the owners, the waters of wells less than 150 feet deep are nearly all hard and some have a distinct taste of iron.

The Eocene strata beneath the alluvial deposits contain water-bearing beds which at Helena have been tapped by numerous wells 450 to 575 feet deep, and by one well 400 feet deep at Barton. The waters rise within 15 to 40 feet of the surface of the lowland, are soft, and of suitable quality for all ordinary domestic and industrial uses. No tests have been made of the character of the Eocene waters at depths exceeding 575 feet or of the deeply buried Cretaceous waters. Waters from depths of 1,000 feet or more are probably under sufficient hydrostatic pressure to produce flows.

Cisterns are used in a few places on the bottom lands. Springs are numerous among the hills of Crowleys Ridge, especially along the foot of the east-facing slope; some of them are used for domestic and farm supplies.

LOCAL SUPPLIES.

Helena.—The city of Helena (population 8,772, census of 1910) is equipped with a water-supply system owned by the Helena Water Co., concerning which information has been furnished by T. J. Mitchell, superintendent. The supply is obtained from four wells about 500 feet in average depth, two being 8 inches and two 10 inches in diameter. The water comes from a bed of coarse, sharp sand between the depths 437 and 500 feet. Several air lifts, each having a daily capacity of 2,000,000 gallons, are used to force the water from the wells to a concrete reservoir holding 1,000,000 gallons, from which it is distributed through 18 miles of mains. The reservoir, which is on Crowleys Ridge west of the town, affords a pressure of 60 pounds per square inch. The daily consumption is 12,000,000 gallons, about one-third of which is used in factories.

Three samples of material from one of the wells of the Helena Water Co., furnished by A. Goldsberg, are on file in the office of the United States Geological Survey (U. S. G. S., well No. 424). One sample from a depth of 350 feet is a drab clay, and two from depths of 455 and 492 feet consist of light-gray clean, sharp quartz sand.

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Detailed information concerning wells at and near Helena owned by the W. D. Reeves Lumber Co. (depth 450 feet), the New South Oil Co. (depth 575 feet), and S. B. Carpenter (depth 575 feet), is given in the table on page 240.

An incomplete log of the well owned by the American Cooperage Co. is given below.

Log of well of American Cooperage Co., 3 miles southwest of the post-office building at Helena.

	Thickness.[a]	Depth.
Quaternary alluvium:	*Feet.*	*Feet.*
Not reported	50	50
Brown sand and gravel, water bearing	110	160
Eocene:		
Firm clay	60	220
White sand, water bearing	12	232
Clay	118	350
White sand, water bearing	40	390
Clay	135	525
White sand, water bearing	50	575

[a] The thicknesses were given from memory and are therefore only approximately correct.

The well was originally drilled to a depth of 700 feet, but the casing was pulled back and the lower 125 feet became filled with sand. The materials between the depths of 575 and 700 feet consisted of white sand with thin, interbedded layers of clay.

In 1879 two borings were made near Helena under the auspices of the United States Mississippi River Commission. One of them (No. 1) was sunk on the Mississippi lowland east of Crowleys Ridge and shows the thickness of the alluvial deposits and the character of the underlying Eocene strata to a depth of 206.4 feet. The other (No. 2) was sunk on Crowleys Ridge and shows the nature of the materials composing the ridge and underlying the ridge to a depth of 236.8 feet. The logs of these borings are repeated here with the age designations modified to accord with present usage.[1]

Log of boring No. 1 in bottom land, Helena.

	Thickness.	Depth.
Quaternary alluvium:	*Feet.*	*Feet.*
Not reported	31	31
Fine sand	56.4	87.4
Coarser sand with gravel	29	116.4
Clean sand with gravel	26.3	142.7
Coarse sand	14.1	156.8
Finer sand	4.7	161.5
Coarse sand	.8	162.3
Eocene (Jackson formation):		
Smooth blue clay	27.2	189.5
Lignite in mass	.2	189.7
Smooth blue clay	16.7	206.4

[1] Report of Profs. E. W. Hilgard and F. V. Hopkins upon the examination of specimens from borings on Mississippi River between Memphis and Vicksburg: Mississippi River Commission Ann. Rept. for 1888, 48th Cong., 1st sess., House Ex. Doc. No. 37, pp. 479–497; logs, pp. 485–488.

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Log of boring No. 2 on Crowleys Ridge, near Helena.

	Thickness.	Depth.
Pleistocene:	*Feet.*	*Feet.*
Brownish-yellow loam, noncalcareous (loess)	0.5	0.5
Yellow silt, calcareous, and full of snail shells and concretions of lime called "loess puppets" (loess)	139.2	139.7
Yellowish clay	28.1	167.8
Pliocene (?) (Lafayette formation?):		
Chert pebbles	3.5	171.3
Eocene (Jackson formation):		
Stiff blue clay with green sand and lignitized seaweed; fossiliferous	27.7	199
Stiff blue clay, calcareous; a clayey greensand marl; fossiliferous	12.2	211.2
Ferruginous concretions of stony hardness	.2	211.4
Clayey greensand marl, with a clay-colored calcareous rock at base; fossiliferous	19.9	231.3
Dark, pebbly, sandy clay with a layer of clay-colored fossiliferous sand at base	5.5	236.8

The molluscan fossils from this well between the depths 171.3 and 236.3 feet, as redetermined by Harris,[1] are:

Helena (boring No. 2): Dentalium (very nearly smooth, but with traces of longitudinal striation); *Volutilithes petrosus* (fragments); *Corbula wailesiana;* Corbula sp.: *Phos hilli* var.; *Pseudoliva vetusta; Pleurotoma denticula;* Actæon; Natica.

According to Harris, these fossils indicate the Jackson age of the containing beds.

In the same boring numerous foraminifers were obtained between the depths 229.5 and 236.8 feet. These were identified and listed by F. V. Hopkins.[2]

The following is the record of a boring at Helena, Ark., made in 1904, under the direction of Capt. E. W. Van C. Lucas, Corps of Engineers, United States Army, by W. M. Rees, assistant engineer:

Log of a boring on the levee at Helena, Ark.

	Thickness.	Depth.
Quaternary alluvium:	*Feet.*	*Feet.*
Artificial fill (levee)	16	16
Blue mud or clay	26	42
Fine blue sand	6	48
Bluish sandy clay	20	68
Fine blue sand, slightly coarser at bottom	8	76
Coarse gray sand with red grains	1.6	77.6
Eocene (?) (Jackson formation?):		
Stiff dark-greenish sandy clay, containing shells and pebbles	1.2	78.8
Hard clay with layers of shale	1.1	79.9
Stiff dark-green sandy clay with shells	3	82.9
Gravel, containing some large pebbles	.6	83.5
Dark-greenish stiff sandy clay, containing shells and large pebbles	1.5	85
Hard brown clay with large pebbles, and with a layer of hard yellow clay at base	19.4	104.4
Hard green clay or marl	1.4	105.8
Siliceous quartzitic rock	.2	106
Dark-green clay with a layer of hard yellow clay at base	2	108
Dark-green clay	1.2	109.2
Hard dark-brown clay	3.6	112.8
Coarse sand, containing shells and lignite	1	113.8
Stiff brown clay with small pebbles and seams of white sand	5.7	119.5
Soft gray sandy clay or fine gray sand	1.5	121

[1] Harris, Gilbert D., The geology of the Mississippi embayment with special reference to the State of Louisiana: Louisiana Geol. Survey, pt. 6, 1902, p. 22 (footnote).
[2] Hilgard, E. W., and Hopkins, F. V., op. cit., pp. 485–488.

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The preceding log, together with the logs of 11 other Government wells bored near the river at Helena and ranging in depth from 50.8 to 90 feet, have been furnished by Capt. Lucas. The elevation of the ground at the points where borings were made ranges from 163 to 192 feet above sea level; all penetrated alluvial sands and clays ranging in total thickness from 50.5 to 89 feet, beneath which hard, green, gray, blue, or dark-brown clay was encountered. The level at which the hard clay was struck ranged from about 99 to 112 feet above sea level. The clay, which is believed to be the upper eroded surface of the Jackson formation (Eocene), corresponds to the uppermost layer of the Eocene in the log just given.

Barton.—At Barton, 13 miles west of Helena, a well drilled to a depth of 926 feet yielded hard water obtained in Quaternary sand and gravel at a depth of 110 feet, and soft water in Eocene sand at a depth of 400 feet. A layer of sandstone was penetrated at a depth of 800 feet and at 926 feet the drill was broken in attempting to penetrate a layer of hard rock. The well was then abandoned and another well was drilled to the 400-foot stratum (No. 1, p. 240) from which an abundant supply of water was obtained.

Southland.—In the vicinity of Southland, which is on the terrace bordering Crowleys Ridge on the west, are several wells ranging in depth from 130 to 140 feet. The log of a well owned by William Russell is as follows (No. 12, p. 240):

Log of well of William Russell, Southland.

	Thickness.	Depth.
Pleistocene alluvium:	*Feet.*	*Feet.*
Red clay	12	12
Blue clay	55	67
Quicksand	65	132
Gravel, water bearing	3	135

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Wells in Phillips County.

	Location.				Owner.	Driller.	Authority.	Date completed.	Approximate elevation above sea level.	Depth.	Diameter.	Depth to principal water-bearing bed.	Depth to other water-bearing beds.	Geologic name of water-bearing formation.
	Place.	T.	R.	Sec.										
									Feet.	*Feet.*	*Inches*	*Feet.*	*Feet.*	
1	Barton (at cotton mill)									400		400	100	Claiborne formation.
2	Helena				Helena Water Co.		T. I. Mitchell		200±	500±	8	480		Do.
3	Helena, 1 mile south of post office.	2 S.	5 E.	9, SE. ¼	W. D. Reeves Lumber Co.	Corless Well Co., Memphis, Tenn.	Owners	1901	200±	450	6			Do.
4	Helena, 3 miles southwest of post office.				American Cooperage Co.	W. P. Maingault, Memphis, Tenn.	Driller	1909	200±	575	4	525	110–160 220–232 350–390	Do.
5	Helena, 3 miles south of (Spanish grant on private survey No. 496).				S. B. Carpenter	W. B. Johnson, Memphis, Tenn.	Dale Welsh	1910	200±	575	4	540	65, 450	Do.
6	Helena, 1 mile south of post office (O'Connor Street and St. Louis, Iron Mountain & Southern Ry.).				New South Oil Co.	J. A. Thedeis, Clarksdale, Miss.	R. T. Doughtie	1911	200±	500	8			Do.
7	Helena, 5 miles west of				C. R. Coolidge	H. H. Rittmann, Stuttgart, Ark.	Driller	1887		43	2			Quaternary alluvium.
8	Helena, 8 miles northwest of.				Dr. Horner	do	do	1887		175	2	175		Eocene.
9	Lexa				St. Louis, Iron Mountain & Southern Ry. Co.		J. R. Stephens, chief engineer.			175	10			Pleistocene alluvium.
10	do				do		do			175	10			Do.
11	North Creek, one-fourth mile northeast of.	1 S.	3 E.		G. F. Foster, Lagrange, Ark.	David Phillips, Lagrange, Ark.	T. W. Foster		210±	95				Do.
12	Southland	1 S.	4 E.		William Russell		Owner		205±	135		70		Eocene.
13	Trenton	2 S.	2 E.	23, SE. ¼	J. L. Kendall	Owner	do			70		70		Pleistocene alluvium.
14	Wabash, one-quarter mile west of.	3 S.	3 E.	31, NW. ¼	Howe Lumber Co.	W. E. Winters, Harrisburg, Ark.	O. D. Howe	1907		50	6	40	20	Quaternary alluvium.

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	Location.				Character of principal water-bearing bed.	Level of water below surface.	Yield per minute.	Method of lift.	Cost of well.	Cost of machinery.	Use.	Quality of water.	Remarks.
	Place.	T.	R.	Sec.									
						Feet.	*Gallons.*						
1	Barton (at cotton mill).	.....	.....	.....	Sand.....	20	.....	.....	.....	.....	.....	Soft.....	
2	Helena.....	.....	.....	.....	Coarse sand.....	18	250?	Air....	.....	.....	Municipal supply.	.....	This well and three other similar wells, having an average depth of 500 feet, furnish the municipal water supply; estimated daily consumption 18,000,000 gallons; analysis 45, p. 302.
3	Helena, 1 mile south of post office.	2 S.	5 E.	9, SE. ¼...	.....	20	.....	...do..	$2,500	$350	Boilers and drinking.	Soft.....	
4	Helena, 3 miles southwest of post office.	.....	.....	.....	White sand.....	20	.....	.....	.....	.....	Domestic and boilers.	.....do.....	
5	Helena, 3 miles south of (Spanish grant on private survey No. 496).	.....	.....	.....	Fine sand.....	27	36	Steam.	1,350		Domestic and manufacturing.	.....do.....	Used for steam production and in vats at plant of American Cooperage Co.
6	Helena, 1 mile south of post office (O'Connor Street and St. Louis, Iron Mountain & Southern Ry.	.....	.....	.....	.....	38	.....	...do..	2,200	182	Domestic and boilers.	.....do.....	
7	Helena, 5 miles west of.	.....	.....	.....	Sand.....	4	7	Hand.	43	5.50	Domestic.....	Hard.....	
8	Helena, 8 miles northwest of.	.....	.....	.....	.....	130	7	Wind.	180		.....do.....	.....do.....	Well is located on Crowleys Ridge.
9	Lexa.....	.....	.....	.....	.....	.....	45	.....	.....	.....	Boilers.....	.....	Analysis 46, p. 302.
10	.....do.....	.....	.....	.....	.....	.....		.....	.....	.....	.....do.....	.....	
11	North Creek, one-fourth mile northeast of.	1 S.	3 E.	.....	.....	25	.....	Hand.	50		Domestic.....	Hard.....	
12	Southland.....	1 S.	4 E.	.....	Gravel.....	38	.....	.....	.....	.....	.....do.....	.....do.....	
13	Trenton.....	2 S.	2 E.	23, SE. ¼...	.....do.....	.....	.....	Gas...	35		.....do.....	.....do.....	
14	Wabash, one-quarter mile west of.	3 S.	3 E.	31, NW. ¼.	Sand and gravel...	7	.....	Steam.	150	150	Domestic and boilers.	.....	Analysis 47, p. 302.

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POINSETT COUNTY.

PHYSIOGRAPHY.

Poinsett County, situated south of Craighead County and east of the northern third of Jackson County, embraces an area of 721 square miles. Its population at the time of the census of 1910 was 12,791. The chief industries are agriculture and lumbering. The agricultural products include cotton, corn, rice, and hay, and such fruits as apples, peaches, and grapes. Rice is grown chiefly on the prairie lands west of Crowleys Ridge. There are numerous sawmills in the county. At Harrisburg are several mills which manufacture wood products.

The county includes parts of the three topographic subdivisions of the Mississippi embayment, Crowleys Ridge, the Advance lowland, and the Mississippi lowland.

Crowleys Ridge is a belt of hilly, partly timbered land, 1 to 3 miles wide, extending in a north-south direction slightly west of the center of the county, and separated from the adjacent plains by sharply defined escarpments; the top of the ridge is 350 to 400 feet above sea level or 100 to 150 feet above the lowlands to the east and west.

West of Crowleys Ridge is a nearly level or gently rolling plain which forms part of the Advance lowland; it is 230 to 290 feet above sea level and slopes slightly to the south. The plain is drained by L'Anguille River, which heads just north of the county and flows southward west of Crowleys Ridge and by Bayou de Vue, which flows from north to south in the western part of the county. The interstream areas present irregularly distributed tracts of open, grass-covered prairies, separated by slightly lower wooded lands. The broad, shallow, flood plains of the streams are in part swampy and, except where cleared for cultivation, are heavily timbered.

East of Crowleys Ridge is the gently undulating, heavily timbered plain of the Mississippi lowland, lying 225 to 240 feet above sea level, sloping slightly to the west and south. This part of the county is drained by St. Francis River, which flows in a sinuous course in a general southerly direction in the eastern part of the county. Much of the surface is swampy, and bayous and ponds are common.

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GEOLOGY.

The core of Crowleys Ridge, to a maximum height of 85 to 100 feet above the level of the lowlands, is composed of irregularly bedded sands and clays, with occasional interstratified layers of lignite, referable to the Wilcox and Claiborne formations of the Eocene; the former outcrops at the base of the ridge from the northern boundary southward to about the middle of the county, and the latter appears at the base of the ridge for the remainder of the distance to the southern boundary. Undifferentiated Eocene deposits containing important water-bearing beds underlie the ridge to an estimated depth of 500 feet or more and extend out to the east and west beneath the alluvial deposits of the lowlands, the thickness of which ranges from 125 to 225 feet.

The Eocene deposits are underlain by strata of Cretaceous age which also contain water-bearing beds. At an unknown depth, estimated, however, to be between 2,000 and 3,000 feet, the Cretaceous deposits rest on a basement of older rocks, probably of Paleozoic age.

In Crowleys Ridge the Eocene strata are overlain unconformably by a few feet to 40 feet of sands and gravels, locally indurated to hard conglomerates, belonging to the Lafayette formation (Pliocene?); these materials are water bearing in many places. The Lafayette is in turn overlain in part by deposits of loess (Pleistocene) reaching 20 feet or more in thickness, which, where present, forms the capping material of the ridge. In this county the loess has in places been removed from the crest of the ridge by erosion, leaving the gravels of the Lafayette as the capping material.

In the Advance lowland the Eocene strata are overlain by an estimated thickness of 125 to 175 feet of Quaternary alluvium of Pleistocene and Recent age. The Pleistocene deposits rest unconformably on the Eocene strata and outcrop at the surface in the interstream areas; they are irregularly bedded, but in general grade downward from loams and silty clays at the surface through fine sands to coarse, water-bearing sands and gravels at the base. The Recent alluvium immediately underlies the flood plains of the present streams. The Mississippi lowland is underlain by 150 to 225 feet of Quaternary alluvial loams, clays, and water-bearing sands and gravels of undifferentiated Pleistocene and Recent age.

WATER RESOURCES.

GENERAL CONDITIONS.

Ordinary supplies.—Water for domestic and industrial uses is obtained chiefly from wells 10 to 160 feet deep; those on the lowlands tap the abundantly water-bearing sands and gravels of the Quater-

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nary alluvial deposits, the waters of which stand 3 to 50 feet below the surface. As reported by the well owners, some of the waters are soft, some are hard, and some are ferruginous. The wells in Crowleys Ridge tap either the water-bearing sands and gravels of the Lafayette formation or the water-bearing sands of the underlying Eocene deposits.

The beds of sand that compose in part the Eocene deposits beneath Crowleys Ridge and underlying the alluvial deposits of the lowlands to an estimated depth of 500 feet or more contain water-bearing beds of importance, the waters of which are under sufficient hydrostatic pressure to lift them within less than 50 feet of the surface, except in the higher parts of Crowleys Ridge; in the Mississippi lowland they rise within a few feet of the surface. The deeply buried Cretaceous water-bearing beds are under hydrostatic pressure, which in the Mississippi lowland is sufficient to cause strong flows at the surface, as shown by the 2,007-foot well at Marked Tree (No. 3, p. 248).

There are a few small springs in Crowleys Ridge, but these do not form an important source of water.

Irrigation.—Wells for irrigating rice lands in the vicinity of Waldenburg, Weiner, and Whitehall (Nos. 11–19, p. 248) range in depth from 75 to 156 feet and yield 300 to 3,000 gallons a minute. The cost of drilling the wells and installing machinery ranges from $500 to $2,800, the average cost based on seven wells being at the rate of $787 for each 1,000 gallons of yield a minute, or at the rate of 79 cents for each gallon of yield a minute.

LOCAL SUPPLIES.

Harrisburg.—The following is the log of a 181-foot well at Harrisburg (population 942, census of 1910); this well is on Crowleys Ridge at the Vandiver Hotel.

Log of well at Vandiver Hotel, Harrisburg.

	Thickness.[a]	Depth.
	Feet.	*Feet.*
Pliocene (?) (Lafayette formation):		
Sand and gravel	20	20
Eocene (Claiborne formation?):		
Hard blue "dry" clay, lignitic near base	80	100
Very fine blue sand, water bearing	80	180

[a] Thicknesses approximate.

Mr. C. H. Winters, a well driller of Harrisburg, has furnished the following log of a well that he drilled on the lowland about one-quarter mile west of the foot of Crowleys Ridge at Harrisburg:

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Log of well in western part of the town of Harrisburg.

	Thickness.	Depth.
	Feet.	*Feet.*
Quaternary alluvium:		
Red clay with loose gravel; contains water in small quantities at base	40	40
Eocene (Wilcox formation):		
Blue "gumbo" clay	25	65
Red sand, very fine and dry, caves easily	40	105
Dark-blue sandy clay containing small fragments of leaves, lignite, shells (?), and decayed wood; emits an unpleasant odor	50	155
Very fine blue sand, water bearing	30	185

The following incomplete log of a well 11 miles northeast of Harrisburg, owned by C. Ripley, has been prepared from a set of well borings, which were furnished by the driller, C. H. Winters, and are now on file in the office of the United States Geological Survey (well No. 1542).

Incomplete log of well of C. Ripley, 11 miles northeast of Harrisburg.

	Thickness.	Depth.
	Feet.	*Feet.*
Quaternary alluvium:		
Gray sandy clay mottled with yellow	20	20
Chunks of drab, slickensided clay	15	35
Same as preceding	(?)	39
Dark shaly carbonaceous clay full of lignitized fragments of vegetation	(?)	42

Marked Tree.—A flowing well, 2,007 feet deep, owned by the town of Marked Tree (population 2,026, census of 1910), was completed in 1911 (No. 3, p. 248). No municipal water-supply system had been installed at the time the information was obtained. Several wells, approximately 400 feet deep, have been drilled at this place (Nos. 4, 5, 6, 7, p. 248). The log of one of them follows:

Log of well of Chapman & Dewey Lumber Co., Marked Tree.

[No. 7, p. 248.]

	Thickness.	Depth.
	Feet.	*Feet.*
Quaternary alluvium:		
"Buckshot" soil grading downward into sand	27	27
Yellowish sand and gravel	193	220
Eocene:		
Soft white clay	12	232
Very hard blue clay	63	295
Soft sandy blue clay with thin layers of sand	71	366
Gray sand	32	398

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Weiner.—Mr. John White, a driller, has furnished the following log of a well owned by the St. Louis Southwestern Railway at Weiner (population 232, census of 1910):

Log of well of the St. Louis Southwestern Railway at Weiner.

	Thickness.	Depth.
[Soil and Pleistocene alluvium]:	*Feet.*	*Feet.*
Soil	0.5	0.5
Light-colored clay	2	2.5
"Hardpan" (clay)	10	12.5
Sand	16	28.5
Quicksand grading downward into coarse sand and gravel, water bearing	22	50.5
Very hard clay	1	51.5
Gravel, becoming coarser as the depth increases, water bearing	50	101.5

Wells for irrigation.—Wells for irrigating rice lands have been drilled in the vicinity of Waldenburg, Weiner, and Whitehall (Nos. 11–19, p. 248); the logs of six irrigation wells follow:

Log of well of Scruggs & Swearengin, 2 miles east of north of Waldenburg.

[No. 11, p. 248.]

	Thickness.	Depth.
Soil and Pleistocene alluvium:	*Feet.*	*Feet.*
Soil	3	3
"Hardpan"	9	12
Fine white sand, water bearing in lower 20 feet	36.5	48.5
Coarse sand grading down into gravel containing scattered fragments of lignite, water bearing	60	108.5

Partial log of well of E. L. Jackson, 2½ miles southwest of Waldenburg.

[No. 12, p. 248.]

	Thickness.	Depth.
Pleistocene alluvium:	*Feet.*	*Feet.*
Not reported	25	25
Fine white sand, becoming coarser, water bearing	30	55
Gravel, water bearing	46	101

Log of well of S. F. Wells, 1 mile north of Weiner.

[No. 14, p. 248.]

	Thickness.	Depth.
Soil and Pleistocene alluvium:	*Feet.*	*Feet.*
Subsoil	1	1
"Hardpan"	30	31
Fine sand, becoming coarser and grading downward into coarse gravel	122	153
Rock	.5	153.5

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Log of well of Chas. Thompson, 1½ miles south of Weiner.

[No. 15, p. 248.]

	Thickness.	Depth.
Pleistocene alluvium:	*Feet.*	*Feet.*
Loam	4	4
"Hardpan"	10	14
Yellow sand	10	24
Fine sand, becoming coarser to a coarse gravel at base, water bearing below the depth of 27 feet	76	100
Coarse gravel with cobbles 6 to 8 inches in diameter, water bearing	56	156

Log of well of Frank Housman, 3 miles northeast of Weiner.

[No. 16, p. 248.]

	Thickness.	Depth.
Soil and Pleistocene alluvium:	*Feet.*	*Feet.*
Light-gray soil	2	2
"Hardpan"	10	12
Fine sand, not water bearing	18	30
Fine sand, becoming coarser to a coarse gravel at base, water bearing	45	75

Log of well of B. A. McKinny, 1½ miles west of Whitehall.

[No. 18, p. 248.]

	Thickness.	Depth.
Soil and Pleistocene alluvium:	*Feet.*	*Feet.*
Soil	2	2
Red "hardpan"	18	20
Gray "hardpan"	6	26
Blue earth, gradually turning to sand	14±	40?
Fine sand, becoming coarser and grading downward into fine gravel, water bearing	80±	120

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Wells in Poinsett County.

	Location.				Owner.	Driller.	Authority.	Date completed.	Approximate elevation above sea level.	Depth.	Diameter.	Depth to principal water-bearing bed.	Depth to other water-bearing beds.	Geologic name of water-bearing formation.
	Place.	T.	R.	Sec.										
									Feet.	*Feet.*	*Inches*	*Feet.*	*Feet.*	
1	Harrisburg				Vandiver Hotel					181		100–180		Wilcox formation.
2	Harrisburg, 1½ miles northeast of.				C. W. Spencer	Owner	Owner	1904	(a)	43	10	37		Lafayette (?) formation.
3	Marked Tree	11 N.	6 E.		Town			1911	236	2,007				Cretaceous.
4	do	11 N.	6 E.		Marked Tree Lumber Co.				236	392	6			Wilcox (?) formation.
5	do	11 N.	6 E.		E. Ritter & Co				236	400	6			Do.
6	do	11 N.	6 E.		Chicago Mill & Lumber Co., Blytheville.	W. B. Johnson, Memphis, Tenn.	W. B. Johnson, Memphis, Tenn.[b]		236	398		366–398		Do.
7	Marked Tree, ½ mile northwest of post office.	11 N.	6 E.	34, NE. ¼ SE. ¼.	Chapman & Dewey Lumber Co.	Johnson & Fleming, Memphis, Tenn.	D. P. Mann and T. G. Staton.	1903	236±	398	6	366–398		Do.
8	Marked Tree, 7 miles southeast of.	10 N.	7 E.	12, NE. ¼..	E. B. Boyd, Monmouth, Ill.		Frank Vollmer, Tyronza.	1908	230±	100	1½	90	45	Quaternary alluvium.
9	Trumann	12 N.	5 E.		Springfield Lumber & Cooperage Co.				237	85	8			Do.
10	do	12 N.	5 E.		do				237	90	4			Do.
11	Waldenburg, 2 miles east of north of.	11 N.	2 E.	18, NW. ¼.	Scruggs & Swearengin, Mooreville, Ind.	Henry Elliott	U. C. Allan	1911	240±	108.5	12	28.5 / 108.5		Pleistocene alluvium.
12	Waldenburg, 2½ miles southwest of.	11 N.	1 E.	35, SE. ¼..	E. L. Jackson		Owner	1910	235±	101	10	60–101	25	Do.
13	Waldenburg, 1½ miles southeast of.	11 N.	2 E.	30, SE. ¼..	John Fahrm	F. L. Casper, Weiner.	do		235±	150	10	32–150		Do.
14	Weiner, 1 mile north of.	12 N.	2 E.	28	S. F. Wells	J. P. Nicholas, Stuttgart.	Driller	1911	240±	153.5	9⅝	80–153.5		Do.
15	Weiner, 1½ miles south of	11 N.	2 E.	17, NW. ¼.	Chas. Thompson	F. L. Casper	Owner	1910	240±	156	10	27–156		Do.
16	Weiner, 3 miles northeast of.	12 N.	2 E.	21, SE. ¼..	Frank Housman	Owner	do	1909	240±	75	4	28–75		Do.
17	Weiner, ¼ mile east of	11 N.	2 E.	4, NW. ¼..	A. L. Wood	F. L. Casper	do	1911	240±	154	9⅝	30–154		Do.
18	Whitehall, 1½ miles west of.	10 N.	3 E.	22	B. A. McKinney	W. C. Winters, Harrisburg.	do	1911		120	8	40–120		Do.
19	Whitehall, 1 mile southeast of.	10 N.	3 E.		Joe Speakes		do			72	30	68–72		Claiborne (?) formation.

[a] Elevation about 100 feet above the level of the St. Louis, Iron Mountain & Southern Ry.
[b] Shepard, E. M., Underground waters of Missouri: U. S. Geol. Survey Water-Supply Paper 195, p. 182, 1907.

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	Location.				Character of principal water-bearing bed.	Level of water above or below surface.	Yield per minute.	Method of lift.	Cost of well.	Cost of machinery.	Use.	Quality of water.	Remarks.
	Place.	T.	R.	Sec.									
						Feet.	*Galls.*						
1	Harrisburg				Fine blue sand	−81					Domestic	Soft	
2	Harrisburg, 1½ miles northeast of.					−37		Hand.			Drinking	Sulphurous	Bored type.
3	Marked Tree	11 N.	6 E.		Sand	+26	300	Flows.				Soft	
4	....do	11 N.	6 E.			− 1.5					Domestic and boilers.		
5	....do	11 N.	6 E.		Sand	− 8	300(?)	Pump			Domestic and manufacture of ice.	Medium soft	
6	....do	11 N.	6 E.		Gray sand	− 3	3				Boilers		
7	Marked tree, ¼ mile northwest of post office.	11 N.	6 E.	34, NE. ¼ SE. ¼.	Sand	− 2		Steam.			Domestic and boilers.		Analysis 48, p. 302.
8	Marked tree, 7 miles southeast of.	10 N.	7 E.	12, NE. ¼	Sand and gravel	−15		Wind.	$136.50		Domestic	Ferruginous	
9	Trumann	12 N.	5 E.		Gravel						Boilers	Hard	
10	....do	12 N.	5 E.		....do						....do	....do	
11	Waldenburg, 2 miles east of north of.	11 N.	2 E.	18, NW. ¼	Sand	−28.5	3,000	Steam.	2,800		Irrigation		Analysis 49, p. 302. 28 feet, 14-inch casing; 20 feet, 12-inch casing; and 60 feet, 12-inch Stancliff strainer.
12	Waldenburg, 2½ miles southwest of.	11 N.	1 E.	35, SE. ¼	Gravel	−25	1,400	...do	1,000		Domestic and irrigation.		Analysis 50, p. 302.
13	Waldenburg, 1½ miles southeast of.	11 N.	2 E.	30, SE. ¼	Sand and gravel			...do	1,000		Irrigation	Hard	74 feet of casing and 76 feet of screen.
14	Weiner, 1 mile north of.	12 N.	2 E.	28	Gravel	−32	2,000	...do	1,350		Domestic and irrigation.	....do	103.5 feet of casing and 50 feet of strainer.
15	Weiner, 1½ miles south of.	11 N.	2 E.	17, NW. ¼	Sand and gravel	−27	2,500	...do	1,400	150	....do	Soft	76 feet of 10-inch casing and 80 feet of 10-inch strainer.
16	Weiner, 3 miles northeast of.	12 N.	2 E.	21, SE. ¼	Sand	−28	300	Gas	500		....do	....do	30 feet of 5-inch casing, 20 feet of 4-inch casing, and 25 feet of 4-inch screen.
17	Weiner, ½ mile east of	11 N.	2 E.	4, NW. ¼	Sand and gravel	−30	2,000	Steam.	900	125	Irrigation	Medium hard.	
18	Whitehall, 1½ miles west of.	10 N.	3 E.	22	....do	−40	800		1,225		Domestic and irrigation.		Analysis 51, p. 302; pit 6 feet square to depth of 40 feet.
19	Whitehall, 1 mile southeast of.	10 N.	3 E.								Domestic	Soft	Dug type.

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PRAIRIE COUNTY.

PHYSIOGRAPHY.

Prairie County, in the east-central part of the State, comprises an area of 675 square miles. Its population was 13,853 in 1910. Agriculture, stock raising, and lumbering are the chief industries. The agricultural products include vegetables, hay, cotton, cereals, and fruits, such as apples, peaches, pears, plums, and berries. Rice is grown extensively and the crop is rapidly increasing in importance.

The county is included within the Advance lowland (see p. 25), the surface of which is in general a gently undulating or rolling plain lying 200 to 240 feet above sea level, and sloping slightly to the south. White River flows a little east of south across the county and leaves it about 10 miles north of the southeastern corner; Cache River forms the eastern boundary for a few miles. The channel of White River is near the western edge of the flood plain, and all the county east of this river is in the heavily timbered flood plain of either White or Cache River, an area characterized by numerous bayous, lakes, and abandoned stream channels. West of White River and north of the Chicago, Rock Island & Pacific Railway much of the surface is timbered land lying a few feet higher than the flood plains and slightly lower than the prairies. South of this railroad and west of the wooded belt bordering White River are broad stretches of grass-covered prairie separated by patches and belts of slightly lower timbered lands.

The principal western tributaries of White River, in order from north to south, are Cypress Creek and its eastward extension, Bayou Des Arc, Wattensaw Bayou, and Bayou Lagrue. Bayou Two Prairie forms the western boundary for a distance of a few miles in the extreme southwest.

GEOLOGY.

Quaternary alluvial deposits of Pleistocene and Recent age immediately underlie the surface of the county to depths of 125 to 180 feet, and rest unconformably on strata of Eocene age. The Pleistocene deposits immediately overlie the Eocene strata and outcrop in the interstream areas; they are irregularly bedded but in general grade downward from fine silty loams and clays at the surface through fine sands to coarse water-bearing sands and gravels at the base. Fossil logs have been encountered in well borings at several places in the county. Loams, clays, sands, and gravels of Recent age constitute the flood-plain materials of the present streams.

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Only meager data are available concerning the character of the Eocene strata underlying the alluvial deposits, but from general considerations it is believed that they consist predominantly of sands and clays, and doubtless they contain water-bearing beds. The Eocene strata are believed to be underlain by strata of Cretaceous age, also in part water bearing, which at an undetermined depth, probably not exceeding 1,200 or 1,500 feet, rest upon a basement of Paleozoic rocks.

WATER RESOURCES.

GENERAL CONDITIONS.

Ordinary supplies.—Water for domestic and industrial uses is obtained chiefly from wells 25 to 180 feet deep that tap the abundantly water-bearing sands and gravels of the Quaternary alluvial deposits, the waters of which stand 10 to 55 feet below the surface. According to the reports of well owners, some of the waters are hard, some are soft, and an occasional one is ferruginous; in general they are of suitable quality for ordinary uses. Well waters having a salty taste have been reported from the northern part of the county in the western half of T. 5 N., R. 5 W.

The waters of the undifferentiated Eocene and Cretaceous deposits, which intervene between the alluvial deposits and the deeply buried Paleozoic basement rocks, may be obtained by means of wells ranging in depth from 200 to an estimated maximum depth of 1,200 or 1,500 feet. These are under hydrostatic pressure sufficient to bring them within less than 50 feet of the surface but not sufficient to cause flows.

Irrigation.—Rice culture was begun in this county shortly after the grain was first successfully grown in the adjoining county of Lonoke and the industry rapidly increased in importance. Water for irrigating the rice lands is obtained from wells 100 to 180 feet deep tapping the water-bearing beds of the alluvial deposits. The water level in these wells is 30 to 55 feet below the surface, and the water is lifted to the surface by means of pumps of large capacity. The cost of sinking the wells and installing pumping plants varies from $750 to $2,200 per well, and the yield ranges from 700 to 3,000 gallons a minute. The average cost based on six wells is at the rate of $1,180 for each 1,000 gallons of yield a minute, or $1.18 for each gallon of yield a minute. Detailed information in regard to nine irrigation wells is given in the table on page 254.

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LOCAL SUPPLIES.

Hazen.—The town of Hazen (population, 687, census of 1910) is equipped with a water-supply system owned by the Hazen Power & Light Co., information concerning which has been furnished by Messrs. W. H. and W. L. Fox. Water is obtained from two wells 60 and 80 feet deep, respectively (Nos. 13 and 14, p. 254). The water, which is hard, is lifted by a pump having a daily capacity of 15,000 gallons and is distributed through 8,000 feet of mains.

The standpipe pressure is 30 pounds per square inch and the direct pressure from the pumps for fire protection is 80 pounds per square inch. The daily consumption is 13,000 gallons for domestic use and 2,000 gallons for manufacturing.

Des Arc.—Logs of two wells at Des Arc (population 1,061, census of 1910) are as follows:

Log of well of Peter Deforest, Des Arc.

[No. 2, p. 254.]

	Thickness.	Depth.
Soil and Pleistocene alluvium:	*Feet.*	*Feet.*
Soil	3.5	3.5
Clay	35	38.5
"Seepy" earth	8	46.5
Red clay	10	56.5
Blue clay	7.5	64
Sand and gravel, water bearing	14	78

Log of well owned by J. W. Pettey, Des Arc.

[No. 3, p. 254.]

	Thickness.	Depth.
Soil and Pleistocene alluvium:	*Feet.*	*Feet.*
Soil	1	1
Clay	3	4
Quicksand	25	29
Joint clay	10	39
Blue clay	8	47
Gray sand	5	52
Sand and gravel, water bearing	20	72

Wells for irrigation.—Wells for irrigating rice lands have been drilled in the vicinity of Devall Bluff, Hazon, and Ulm, detailed information concerning some of which is given in the table on page 254. The following are logs of two irrigation wells:

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Log of well of Thomas Bros., 3½ miles west of Devall Bluff.

[No. 10, p. 254.]

	Thickness.	Depth.
Soil and Pleistocene alluvium:	*Feet.*	*Feet.*
Soil	1	1
Red clay	59	60
Blue clay	33	93
Sand	22	115
Sand and gravel, water bearing	61	176
Eocene:		
Blue clay	3	179

Log of well of Mr. Avery, 2 miles southeast of Hazen.

[No. 15, p. 254.]

	Thickness.	Depth.
Soil and Pleistocene alluvium:	*Feet.*	*Feet.*
Soil and red clay	25	25
Fine red sand	46	71
Blue clay	29	100
Fine sand	6	106
Sand and gravel	15	121
Fine hard sand	13	134
Sand and gravel, water bearing; stopped on blue clay which is probably of Eocene age	42	176

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Wells in Prairie County.

	Location.				Owner.	Driller.	Authority.	Date completed.	Approximate elevation above sea level.	Depth.	Diameter.	Depth to principal water-bearing bed.	Depth to other water-bearing beds.	Geologic name of water-bearing formation.
	Place.	T.	R.	Sec.										
									Feet.	*Feet.*	*Inches*	*Feet.*	*Feet.*	
1	Carlisle (Lonoke Co.), 8 miles southeast of (in Prairie Co.).	1 N.	6 W.	8, SW. ¼	Hubbard & Sons.	M. Brown	W. O. Hubbard.	1910	.....	155	24	70–155	.....	Pleistocene alluvium.
2	Des Arc, ½ mile north of post office.	4 N.	5 W.	.....	Peter Deforest	J. W. Pettey	Owner	1909	.....	78	2	64–78	.....	Do.
3	Des Arc	.....	.....	.....	J. W. Pettey	Owner	.....do	1908	(a)	72	2	50–72	30	Do.
4	.....do	4 N.	5 W.	14, NE. ¼	G. W. Edmondson	J. W. Pettey	.....do	1906	.....	75	2	65–75	.....	Do.
5	Des Arc, ½ mile southeast of post office.	.....	.....	.....	McQueen & Fink	.....do	J. H. McQueen	1908	(b)	70	4	55–70	.....	Do.
6	Devall Bluff	.....	.....	.....	F. Gates	.....	.....	.....	.....	95	.....	.....	.....	Do.
7	.....do	.....	.....	.....	E. L. Sanders	.....	.....	.....	.....	75	.....	.....	.....	Do.
8	Devall Bluff, ½ mile south of.	.....	.....	.....	Jacob Frohlich	.....	.....	.....	.....	75	.....	.....	.....	Do.
9	Devall Bluff	.....	.....	.....	W. B. Coyle	.....	.....	.....	.....	85	.....	.....	.....	Do.
10	Devall Bluff, 3½ miles west of.	.....	.....	.....	Thomas Bros., Hazen.	Wm. Guntzenhouser, Stuttgart.	Clay Thomas, Hazen.	1911	230±	179	12	130–179	.....	Do.
11	Devall Bluff, 5 miles southwest of.	.....	.....	.....	Mrs. Geo. Lawman, Hazen.	Ralph Canyon, Hazen.	Owner	.....	300±	150	12	90–150	.....	Do.
12	Devall Bluff, 8½ miles south of.	1 N.	5 W.	24, E. ½	Chas. Strohl, Hazen.	Wheeler & Pettey, Devall Bluff.	.....do	1910	.....	112	8¼	75–112	.....	Do.
13	Hazen	.....	.....	.....	Hazen Power & Light Co.	J. J. Paduska	W. L. Fox	1908	.....	60	4	.....	.....	Do.
14	.....do	.....	.....	.....	.....do	.....do	.....do	1911	.....	80	6	.....	.....	Do.
15	Hazen, 2 miles southeast of.	.....	.....	.....	Mr. Avery	.....	E. G. Norton, Brinkley.	.....	235±	176	.....	.....	.....	Do.
16	Hazen, 2½ miles west of.	2 N.	6 W.	23, NW. ¼	E. W. Crouch	W. M. Scheck, Memphis, Tenn.	Owner	1909	.....	127	8	80–127	.....	Do.
17	Hazen, 8 miles southwest of.	1 N.	6 W.	18, SW. ¼	W. A. Shaw	Layne & Bowler, Stuttgart.	.....do	1910	.....	133	11⅝	77–133	.....	Do.
18	Hazen, 6 miles southwest of.	1 N.	6 W.	6	T. E. Downs, Carlisle.	J. E. Gildrey, Rayne, La.	.....do	.....	.....	150	8	.....	.....	Do.
19	Hazen, 8 miles southwest of.	1 N.	6 W.	18, SW. ¼	C. H. Chapman	Lonoke	E. L. Chapman.	1904	212±	158	9⅝	.....	.....	Do.
20	Ulm, 1 mile west of	1 S.	4 W.	.....	A. J. Liedtke, Stuttgart.	Layne & Bowler, Stuttgart.	Owner	1910	209±	150	11⅝	45–150	.....	Do.

a Elevation about 40 feet above low-water level of White River.

b Elevation about 20 feet above low-water level of White River.

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	Location.				Character of principal water-bearing bed.	Level of water below surface.	Yield per minute.	Method of lift.	Cost of well.	Cost of machinery.	Use.	Quality of water.	Remarks.
	Place.	T.	R.	Sec.									
						Feet.	*Galls.*						
1	Carlisle (Lonoke Co.), 8 miles southeast of (in Prairie Co.).	1 N.	6 W.	8, SW. ¼	Sand and gravel	28	4,000		$5,000		Irrigation	Soft	
2	Des Arc, ½ mile north of post office.	4 N.	5 W.		do	35			50	18	Domestic		
3	Des Arc				do	35		Hand.	50		do		
4	do	4 N.	5 W.	14, NE. ¼	Gray sand	40		do	55	6	do	Soft and ferruginous.	
5	Des Arc, ½ mile southeast of post office.				Sand	20		Steam.	125	110	Domestic and manufacture of ice.	Soft	
6	Devall Bluff										Domestic		Assay 44, p. 304.
7	do										do		Assay 45, p. 304.
8	Devall Bluff, ½ mile south of.										do		Assay 46, p. 304.
9	Devall Bluff										do		Assay 47, p. 304.
10	Devall Bluff, 3½ miles west of.				Sand and gravel	50	1,800	Steam.	1,850		Irrigation		At top 80 feet of 10-inch casing and at bottom 99 feet of 12-inch casing and screen. Analysis 52, p. 302.
11	Devall Bluff, 5 miles southwest of.				Gravel	47	3,000				Domestic and irrigation.	Hard	Steel pit 95 feet deep and 28 inches in diameter; 60 feet of 12-inch strainer.
12	Devall Bluff, 8½ miles south of.	1 N.	5 W.	24, E. ½	Sand and gravel	48		Steam.	600		do	Soft	102 feet of 8¼-inch casing.
13	Hazen						200	Gas			Municipal supply.		Combined yield of these 2 wells furnishes the municipal water supply. For well No. 14, see analysis 53, p. 302.
14	do						250	do	400		do		
15	Hazen, 2 miles southeast of.					55		Electricity.			Irrigation		
16	Hazen, 2½ miles west of	2 N.	6 W.	23, NW. ¼	Sand and gravel	47½	700	Steam.	600	150	do		Analysis 54, p. 302.
17	Hazen, 8 miles southwest of.	1 N.	6 W.	18, SW. ¼	do	34	1,800		1,300	650	do	Soft	
18	Hazen, 6 miles southwest of.	1 N.	6 W.	6	Gravel	35	700	Air	600	1,000	do	Hard	
19	Hazen, 8 miles southwest of.	1 N.	6 W.	18, SW. ¼	do	33	2,000		1,200	125	Domestic and irrigation.		Irrigates 300 acres. Analysis 55, p. 302.
20	Ulm, 1 mile west of	1 S.	4 W.		Fine sand	40	1,200	Steam.	2,200		do	Soft	110 feet of casing and 40 feet of screen.

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PULASKI COUNTY.

PHYSIOGRAPHY.

Pulaski County, in the central part of the State, has an area of 747 square miles and a population, according to the census of 1910, of 86,751. Only that part of the county lying east of Arkansas River and east of the Ozark province is treated in detail in this report. Agriculture is the chief industry and the principal crops are cotton, cereals, vegetables, and hay

The greater part of the county lying west of the St. Louis, Iron Mountain & Southern Railway is included in the Ozark province, an area characterized by hills and ridges which trend in general east and west, the summits of which are 500 to 1,000 feet or more above sea level. The remainder of the county is part of the Gulf Coastal Plain, here topographically subdivisible into the upland west of the Arkansas River bottom, a small area of Tertiary upland near Jacksonville, and the Advance lowland. The hills of the upland west of Arkansas River are 400 to 500 feet above sea level, but the upland has been strongly dissected by Fourche and Loran creeks and their tributaries.

The Arkansas River flood plain forms the greater part of the Advance lowland, a flat or gently rolling, heavily timbered plain, which stands 230 to 250 feet above sea level, and in which swamps, lakes, abandoned stream channels, and bayous are numerous. Arkansas River crosses the county, flowing southeastward to a point a few miles beyond Little Rock, where its general course becomes southerly.

In the northern part of the lowland small interstream areas rise a few feet above the flood-plain level.

GEOLOGY.

Paleozoic rocks of Ordovician and Carboniferous age outcrop in the Ozark province. They are separated from the deposits of the Coastal Plain by a steep southeastward-dipping erosion escarpment which trends northeast-southwest within a few miles west of the St. Louis, Iron Mountain & Southern Railway. Along the line of this escarpment the upper eroded surface of the Paleozoic rocks passes under the deposits of the Coastal Plain and extends southeastward beneath them.

Strata of Tertiary age, including the Midway formation (Eocene) and overlying undifferentiated Eocene deposits, outcrop in the Coastal Plain upland west of Arkansas River. The Midway formation, which consists of 25 feet or more of limestones, calcareous sandstones, sands, and clays, outcrops in a narrow area along the northwestern margin of the Coastal Plain, where it rests unconformably on Pale-

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ozoic rocks. The undifferentiated Eocene deposits, which consist of unconsolidated sands and clays, overlie the Midway formation and come to the surface in the upland southeast of the Midway area and also in a small area in the vicinity of Jacksonville, in the northeastern part of the county. Two to 5 miles south of Little Rock is a hill composed of igneous rocks which project through the Tertiary deposits. The summit of the hill is about 500 feet above sea level.

The Tertiary deposits are underlain by strata of Cretaceous age which at Little Rock have been recognized in well excavations and questionably recognized in a few poorly exposed outcrops. The materials immediately underlying the Arkansas River bottom to estimated depths of 100 to 200 feet consist of Quaternary alluvial loams, clays, sands, and gravels which contain large quantities of water. These deposits rest on undifferentiated strata of Cretaceous and Eocene age which at undetermined depths rest on the southeastward-sloping Paleozoic basement rocks.

WATER RESOURCES.

GENERAL CONDITIONS.

East of Arkansas River water for domestic and industrial uses is obtained chiefly from wells 15 to 100 feet deep that tap the sands and gravels of the Quaternary alluvium the waters of which stand 8 to 30 feet below the surface. According to well owners, many of the waters are hard, but some are soft and some are ferruginous. Detailed information concerning wells at Argenta and at Jacksonville is given in the table on page 260. A flowing well 140 feet deep has been obtained at Sweet Home, a village west of Arkansas River on the St. Louis, Iron Mountain & Southern Railway, about 6½ miles southeast of Little Rock (No. 14, p. 260).

The undifferentiated Eocene and Cretaceous deposits intervening between the alluvial deposits and the buried Paleozoic basement rocks, except in close proximity to the margin of the Ozark province, doubtless contain water-bearing beds that are a probable source of artesian waters. These waters are under hydrostatic pressure probably sufficient to bring them within less than 50 feet of the surface, but it is doubtful if flowing wells can be obtained in the Advance lowland east of Arkansas River. The static head of the flowing well at Sweet Home is believed to be due to conditions that are only of local extent.

LOCAL SUPPLIES.

Little Rock.—The municipal water supply of Little Rock (population 45,914, census of 1910) is obtained from Arkansas River. Information concerning the system has been furnished by Mr. G. M. Gadsby, superintendent of the waterworks, and by Mr. George P. Brown, secretary of the board of trade. The raw water is first

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pumped into a preliminary sedimentation basin (holding 2,500,000 gallons) where 20 to 60 per cent of the suspended matter is removed by subsidence. The water drawn from the top of this basin at one end is led into a coagulating basin having a capacity of 5,000,000 gallons, arranged with baffles and weirs so as to allow the most efficient settling of the coagulated water. From this coagulating basin the water is drawn by floating outlets to the filters, the pressure filters being placed at a lower elevation so that the water flows through them into the clear-water basin by gravity. The clear-water basin has a capacity of 5,300,000 gallons and is situated at such elevation that the city is supplied therefrom by gravity. Twenty-five closed pressure filters and four open gravity filters, all of the rapid-sand type, have been installed, the pressure filters having a total sand surface of 2,284 square feet and the gravity filters a total sand surface of 704 square feet. The sand is agitated during washing by the wash water, which is forced in from the bottom of the filter at sufficient pressure to float the sand almost to the top of the outlet trough. The normal capacity of the plant is 8,504,000 gallons and the daily consumption is about 4,000,000 gallons. Alum and iron and lime are used as coagulants, the kind and quantity of the coagulant varying with the quality of the raw water. The filtered water is also treated with calcium hypochlorite as it enters the clear-water basin. Though it is not intended to soften the water it is frequently necessary at low stages to use sufficient lime to have some softening effect. The water varies widely in its mineral content, but though enough chlorine has been present at times to be slightly noticeable the water has never been reported as brackish. It is generally used in boilers and is reported to be satisfactory with moderate use of boiler compound. There are 90 miles of mains, about 8,000 taps, and about 450 fire hydrants.

Argenta.—The town of Argenta (population, 11,138, census of 1910) is equipped with a water-supply system owned by the American Waterworks & Guaranty Co. Information concerning it has been obtained from F. G. Smith, acting superintendent. The supply is obtained from wells that tap the Quaternary alluvial deposits and are capable of yielding 2,000,000 gallons daily. There are 25 miles of mains. A pressure of 55 pounds per square inch is ordinarily maintained, but this can be raised for fire protection to 100 pounds per square inch. The daily consumption is 500,000 gallons.

The St. Louis, Iron Mountain & Southern Railway Co. owns nine wells at Argenta, all of which are described in detail in the table on page 260 (Nos. 1–9). One well is at the site of the new shops and the other eight form a group used in furnishing the boiler supply of locomotives. The logs of three of these wells are as follows:

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Logs of wells of St. Louis, Iron Mountain & Southern Railway, Argenta.

At site of new shops.

[No. 1, p. 260.]

	Thickness.	Depth.
Quaternary alluvium:	*Feet.*	*Feet.*
Loam	4	4
Quicksand	3	7
Red clay	10	17
"Hardpan" or clay	20	37
Sandy clay	13	50
Quicksand	20	70
Gravel, water bearing	4	74
Coarse sand and bowlders, water bearing	6	80

Well No. 1 in group.

[No. 2, p. 260.]

	Thickness.	Depth.
Artificial fill:	*Feet.*	*Feet.*
Cinders and clay	10	10
Quaternary alluvium:		
"Dry" sand and clay	30	40
Sand and gravel, water bearing	40	80

Well No. 4 in group.

[No. 5, p. 260.]

Artificial fill:		
Cinders and clay	10	10
Quaternary alluvium:		
Fine sand	25	35
Very fine sand	20	55
Sand and gravel	25	80

The materials penetrated in wells Nos. 2, 3, 6, 7, and 8 of the group were of the same character as those encountered in well No. 1, and those in well No. 5 of the group were of the same character as those in well No. 4.

Jacksonville.—The log of a well owned by S. Taylor, seven-eighths of a mile south of Jacksonville, is as follows:

Log of well of S. Taylor, seven-eighths of a mile south of Jacksonville (SE. ¼ sec. 30, T. 3 N., R. 10 W.).

	Thickness.	Depth.
Quaternary alluvium:	*Feet.*	*Feet.*
Hard red clay	7	7
White clay	4	11
Variegated clay; stopped on soft, water-bearing sand	13	24

The log of an 82-foot well at Jacksonville, on the property of A. J. McBride, drilled in 1904, has been furnished by the owner as follows:

Log of well of A. J. McBride, Jacksonville.

	Thickness.	Depth.
[Quaternary alluvium]:	*Feet.*	*Feet.*
Red gumbo	10	10
Gray clay	20	30
Black clay	40	70
[Eocene (Midway formation ?)]:		
Limestone (?), water bearing	12	82

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Wells in Pulaski County.

	Location.	Owner.	Driller.	Authority.	Date completed.	Approximate elevation above sea level.	Depth.	Diameter.	Depth to principal water-bearing bed.	Geologic name of water-bearing formation.	Character of principal water-bearing bed.	Level of water below surface.	Method of lift.	Cost of well.	Cost of machinery.	Use.	Quality of water.	Remarks.
						Feet.	*Ft.*	*In.*	*Feet.*			*Ft.*						
1	Argenta (at site of railroad shops).	St. Louis, Iron Mountain & Southern Ry. Co.	.....	J. R. Stephens, chief engineer.	....	255±	80	....	50–80	Quaternary alluvium.	Sand and gravel.	32	.....	.....	.....	.....	.....	
2	Argenta (well No. 1)	.....do.....	.....	...do.....	1907	255±	80	10	40–80	...do	...do.....	....	.....	.....	.....	Boilers...	.....	The combined yield of these 8 wells is 60,000,000 gallons per month. They are equipped with No. 8 and No. 10 Cook strainers, 15 to 20 feet in length.
3	Argenta (well No. 2)	.....do.....	.....	...do.....	1907	255±	79	10	40–80	...do	...do.....	....	.....	.....	.....	...do.....	.....	
4	Argenta (well No. 3)	.....do.....	.....	...do.....	1907	255±	80	10	40–80	...do	...do.....	....	.....	.....	.....	...do.....	.....	
5	Argenta (well No. 4)	.....do.....	.....	...do.....	1907	255±	80	10	55–80	...do	...do.....	....	.....	.....	.....	...do.....	.....	
6	Argenta (well No. 5)	.....do.....	.....	...do.....	1907	255±	81	10	55–80	...do	...do.....	....	.....	.....	.....	...do.....	.....	
7	Argenta (well No. 6)	.....do.....	.....	...do.....	1907	255±	82	10	40–80	...do	...do.....	....	.....	.....	.....	...do.....	.....	
8	Argenta (well No. 7)	.....do.....	.....	...do.....	1907	255±	80	10	40–80	...do	...do.....	....	.....	.....	.....	...do.....	.....	
9	Argenta (well No. 8)	.....do.....	.....	...do.....	1907	255±	78	10	40–80	...do	...do.....	....	.....	.....	.....	...do.....	.....	
10	East Little Rock....	.....do.....	C. H. Winters.	Driller [a].	....	268	66	8	.....	Quaternary	.....	27	.....	.....	.....	.....	Hard	Paleozoic rock struck at depth of 66 feet.
11	Jacksonville.....	Mrs. P. T. Murtishaw.	B. Wood..	S. W. Murtishaw.	1881	288±	86	4	.....	Quaternary alluvium.	Sand.....	30	Hand	$160	$60	Domestic	..do .	
12	.....do	Jacksonville Gin Co.	H. L. Huff, Little Rock.	J. H. Ramsey.	....	288±	150	8	.....	...do	.....	....	.....	.....	.....	.....	.....	This well entered rock, probably of Paleozoic age, at a depth of 30 feet. An insufficient supply of water was obtained.
13	Scott.....	C. F. Chaer...	.....	.....	....	.....	42	....	.....	...do	.....	....	.....	.....	.....	Domestic	.....	Assay 52, p. 304.
14	Sweet Home (at mill)	Mr. Bowman .	J. P. Clifford.	Driller [a]..	....	250?	140	....	.....	Eocene.	.....	....	Flows	....	....	.....	Soft.	Water from below a bed of black clay.
15	Wrightsville.....	Wm. Ferral...	...do.....	...do.....	....	257	120	....	.....	...do	.....	....	.....	.....	.....	.....	..do .	

[a] Veatch, A. C., Geology and underground water resources of northern Louisiana and southern Arkansas: U. S. Geol. Survey Prof. Paper 46, pp. 194–195, 1906.

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RANDOLPH COUNTY.

PHYSIOGRAPHY.

Randolph County, which lies west of Clay and Green counties and north of Lawrence County, embraces an area of 674 square miles. Its population at the time of the census of 1910 was 18,987. Agriculture is the chief industry, the products including cotton, cereals, vegetables, and hay.

About three-quarters of the total area of the county is included in the Ozark province, a hilly upland lying 400 feet or more above sea level. A triangular area in the southeast, embracing about one-fourth of the county, is included in the Advance lowland, a topographic subdivision of the Mississippi embayment. Only that part of the county east of the Ozark province, including approximately one-third of the area, is treated in this report.

The surface of the Advance lowland is a nearly level or gently rolling plain, 270 to 280 feet above sea level, separated from the Ozark province on the west by a well-defined escarpment. Black River flows across the plain from the eastern border of the county westward to Pocahontas, and thence follows along the foot of the Ozark Hills to the southern boundary of the county. Near Pocahontas Black River is joined by Current River, which flows across the plain from northeast to southwest. The greater part of the Advance lowland is included in the broad timbered flood plains of these two streams, although in the extreme southeastern part of the county is a small area of gently rolling white clay land having the characteristics of the interstream areas.

GEOLOGY.

The Ozark province is underlain by Paleozoic rocks of Cambrian and Lower Ordovician age, which are separated from the deposits of the Coastal Plain on the east by a steep, southeastward-dipping, erosion escarpment, trending northeast-southwest. The older rocks pass under the deposits of the Coastal Plain and extend eastward beneath them, reaching greater depths in that direction.

The Advance lowland is underlain by an estimated thickness of 150 to 180 feet of Quaternary alluvial deposits of Pleistocene and Recent age. The Pleistocene deposits rest on strata of Eocene or Cretaceous age and outcrop in the interstream areas. In general they grade downward from silty loams or clays at the surface through fine sands to coarse, water-bearing sands and gravels at the base. The Recent alluvium appears at the surface in the flood plains of Black and Current rivers.

The strata of Eocene or Cretaceous age do not outcrop in the county. They underlie the alluvium which is underlain in turn by

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a basement of Paleozoic rocks the depth of which has not been determined by borings but probably nowhere exceeds 500 or 600 feet. The Eocene and Cretaceous deposits consist chiefly of unconsolidated sands and clays.

WATER RESOURCES.

In the Advance lowland water for domestic use is obtained chiefly from wells 15 to 100 feet deep, which tap the water-bearing sands and gravels of the Quaternary alluvium. The water stands in the wells 10 to 30 feet below the surface. As reported by the owners the well waters are in general soft but locally they are ferruginous.

Two wells owned by the St. Louis, Iron Mountain & Southern Railway Co. at O'Kean are, respectively, 50 and 97 feet deep, and 8 and 10 inches in diameter; the water is used in the boilers of locomotives. the consumption being 1,200,000 gallons per month. An analysis of the mixed waters from the two wells is given in the table opposite page 302 (No. 57).

The Eocene and Cretaceous deposits which underlie the alluvium are believed to contain water-bearing beds which could be reached by wells ranging in depth from 180 to 500 or 600 feet as a probable maximum. The hydrostatic pressure would probably be sufficient in most places to bring the waters within less than 50 feet of the surface but not sufficient to cause flows.

ST. FRANCIS COUNTY.[1]

PHYSIOGRAPHY.

St. Francis County, in the eastern part of the State, comprises an area of 628 square miles and has a population, according to the census of 1910, of 22,548. Agriculture and lumbering are the principal industries. The agricultural products include cotton, cereals, and hay. Sawmills are numerous.

Three topographic subdivisions of the Gulf Coastal Plain are represented in the county—Crowleys Ridge, the Advance lowland, and the Mississippi lowland.

Crowleys Ridge is a belt of hilly, partly wooded land, 1½ to 6 miles wide, trending north and south a little west of the center of the county; the crest of the ridge is about 370 feet above sea level, or 140 to 160 feet above the lowlands to the east and west. The drainage is effected chiefly by small streams that flow either eastward into St. Francis River or westward into L'Anguille River, but Big Crow Creek heads in the ridge near the northern boundary of the county. flows due south for about 9 miles, and leaves the ridge to join St.

[1] A detailed account of the surface features and the geology of St. Francis County, accompanied by a topographic and a geologic map, is given by R. E. Call in Arkansas Geol. Survey Ann. Rept. for 1889, vol. 2, pp. 143–183.

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Francis River near Madison. Both the eastern and western slopes of the ridge are sharply defined, but the eastern slope is the steeper.

The part of the county west of Crowleys Ridge is included in the Advance lowland, a gently undulating plain 230 to 260 feet above sea level. L'Anguille River traverses this plain from north to south at a distance of 3 to 6 miles west of Crowleys Ridge. From the foot of the ridge westward to L'Anguille River the plain is heavily timbered, except where cleared for cultivation, and slopes gradually from an elevation of about 260 feet to about 220 feet. West of the river the plain slopes from an elevation of about 250 feet in the north to about 230 feet in the south. A small area in the southwestern part of the county is drained by Big Creek, a tributary of White River. The flood plains of the streams are heavily timbered and in part swampy. The interstream areas west of L'Anguille River present irregular patches of open, grass-covered prairie land, separated by slightly depressed patches and belts of timbered land.

The part of the county east of Crowleys Ridge is included in the Mississippi lowland, a heavily timbered, nearly level or gently undulating plain, 220 to 230 feet above sea level; swamps, lakes, bayous, and abandoned stream channels are numerous. The drainage is effected by St. Francis River, which flows from north to south in the western part of the lowland, following a course which in detail is very sinuous. Much of the area is subject to overflow from St. Francis and Mississippi rivers.

GEOLOGY.

Strata of Eocene age compose the core of Crowleys Ridge to a height of 20 to 70 feet above the level of the lowlands to the east and west. The deposits are irregularly bedded, dark to light clays, in part lignitic, and subordinate beds of dark to light-colored sands, in part glauconitic. Locally, the clays contain large numbers of invertebrate fossils, of which *Ostrea alabamiensis* Lea is the most abundant and most conspicuous species. The fossiliferous stratum has been determined by Vaughan to be of lower Jackson age. (See p. 82.) Undifferentiated strata of Eocene age underlie Crowleys Ridge to an estimated depth of 800 or 1,000 feet, and beds of this age extend out under the lowlands both to the east and west of the ridge, where they are overlain by Quaternary alluvium, whose estimated thickness ranges from 125 to 225 feet. The Eocene deposits contain important water-bearing beds, that have been tapped by deep wells at Forrest City. The Eocene deposits are underlain by deposits of Cretaceous age, which are thought to contain water-bearing beds; at an undetermined depth, probably, however, not exceeding 3,000 feet, the Cretaceous strata rest upon a basement of rocks believed to be of Paleozoic age.

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The Eocene strata of Crowleys Ridge are unconformably overlain by 10 to 40 feet of coarse sands and gravels, in part water-bearing, belonging to the Lafayette formation (Pliocene?) and this formation is in turn overlain by loess of Pleistocene age, ranging in thickness from a few feet to 80 feet or more. The loess is the capping material of the ridge. Both the Lafayette and the loess are found blanketing the slopes of the ridge; in places these materials have reached their present position either by redeposition, landslides, or creep, but at many places it is difficult to distinguish between the original and the disturbed deposits.

The Quaternary alluvium which immediately underlies the surface in the Advance lowland west of Crowleys Ridge to depths of 140 to 200 feet is in part of Pleistocene and in part of Recent age. The Pleistocene deposits which outcrop in the interstream areas are irregularly bedded but in general grade downward from fine loams and silty clays through fine sands to coarse, abundantly water-bearing sands and gravels which rest unconformably on Eocene strata. The Recent deposits are loams, clays, sands, and gravels forming the flood-plain materials of the present streams.

The Quaternary alluvium, which underlies the Mississippi lowland to depths estimated at 125 to 225 feet, consists of loams, clays, and gravels, the coarser portions of which are abundantly water bearing. The materials immediately beneath the surface are probably entirely of Recent age, but Pleistocene beds probably intervene between the Recent and the underlying Eocene strata.

WATER RESOURCES.

GENERAL CONDITIONS.

Ordinary supplies.—Water for domestic and industrial use is obtained chiefly from wells 20 to 200 feet deep. Wells in Crowleys Ridge tap either the water-bearing sands and gravels of the Lafayette formation or the water-bearing sands of the underlying Eocene deposits, the waters of which rise within 20 to 125 feet of the surface. Wells in the lowlands tap the water-bearing sands and gravels of the Quaternary alluvium. According to the reports of the owners most of the well waters are hard and some are strongly ferruginous, but a few are soft.

The Eocene strata that underlie Crowleys Ridge to an estimated depth of 800 to 1,000 feet and extend out to the east and west of the ridge beneath the Quaternary alluvium, contain water-bearing beds in which the waters are under hydrostatic pressure; in Crowleys Ridge they will rise within less than 150 feet of the surface, in the lowland east of the ridge within less than 20 feet of the surface, and in the lowland west of the ridge within 30 to 60 feet of the surface.

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The deeply buried Cretaceous deposits are believed to contain water-bearing beds which would be reached by wells 1,000 feet or more in depth. In the Mississippi lowland waters from depths of 1,200 feet or more would probably be under sufficient hydrostatic pressure to flow at the surface.

Small springs are numerous in Crowleys Ridge and are utilized to some extent for domestic and farm supplies.

Irrigation.—Rice culture has become an important industry on the prairies in the western part of the county, and water for irrigating the rice lands is obtained from wells 125 to 190 feet deep. The cost of sinking the wells and installing pumping plants ranges from $1,000 to $3,500 per well, and the yield ranges from 600 to 2,500 gallons a minute. The average cost based on nine wells is at the rate of $1,276 for each 1,000 gallons of yield a minute, or $1.28 for each gallon of yield a minute.

Detailed information concerning 14 irrigation wells is given in the table on page 268.

LOCAL SUPPLIES.

Forrest City.—Forrest City (population, 2,484, census of 1910) is equipped with a water supply drawn from three wells, respectively, 425, 425+, and 450 feet in depth (Nos. 3–5, p. 268). The principal water-bearing bed is in Eocene deposits at a depth of 400 feet, and the water rises within 70 feet of the surface. The standpipe pressure is 70 pounds per square inch. The wells yield an adequate supply of water of satisfactory quality.

A well at the Choctaw Brick Plant, three-quarters of a mile east of the town, is 600 feet deep and taps a water-bearing bed in the Eocene deposits (No. 6, p. 268).

Wells for irrigation.—Wells for irrigating rice lands have been drilled in the western part of the county in the vicinity of Goodwin, Wheetley, and east and northeast of Zent (Monroe County). A. Boysen & Sons own nine wells near Wheetley, in Tps. 3 and 4 N., R. 1 W. (See No. 11, p. 268.) Mr. A. Boysen states that the wells pass through essentially the succession of strata given in the following log:

Average log of nine wells of A. Boysen & Sons near Wheetley.

	Thickness.	Depth.
Soil and Pleistocene alluvium:	*Feet.*	*Feet.*
Soil	3	3
Hard clay, almost impervious to water	12	15
Sand, slightly argillaceous	15	30
Quicksand	10	40
Sand, becoming coarser toward base, water bearing	30	70
Gravel, becoming coarser toward base, water bearing; drilling is discontinued when clay is struck at a depth of 145 feet	75	145

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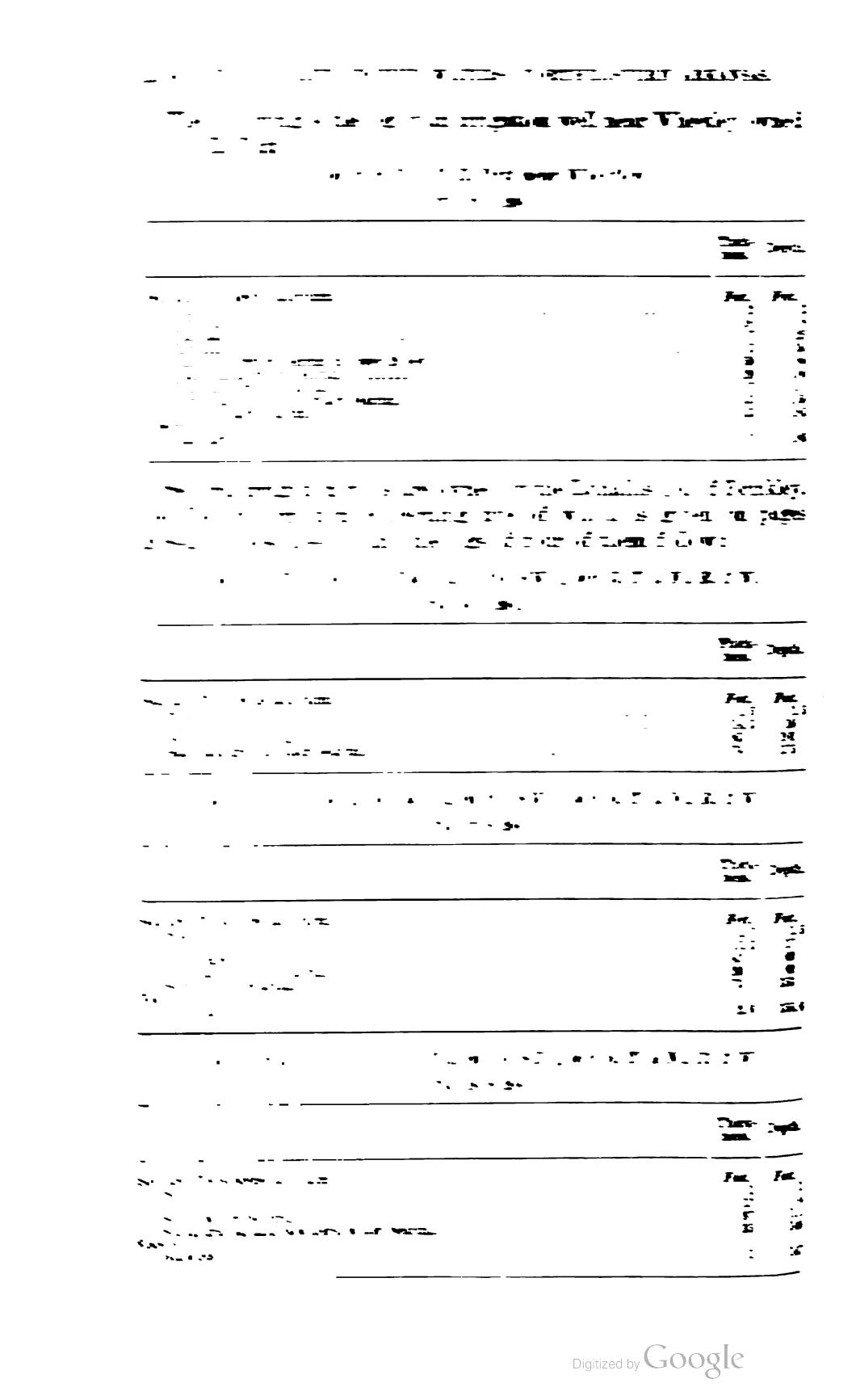

Log of well of the Luhallis Co., in the SE. ¼ sec. 6, T. 4 N., R. 1 W.

[No. 19, p. 268.]

	Thickness.	Depth.
Soil and Pleistocene alluvium:	*Feet.*	*Feet.*
Soil	1.5	1.5
Clay	14.5	16
Quicksand	39	55
Fine sand, water bearing	30	85
Fine sand and fine gravel, water bearing	60	145
Eocene:		
Blue clay	2	147
Blue sand	16	163
Blue clay	165	328
Sand, water bearing	50	378
Blue shale	84	462

The last well was drilled to the depth indicated (462 feet) to determine if larger quantities of water could be obtained from deeper water-bearing beds than from the sands and gravels of the alluvial deposits, with negative results.

The logs of three other irrigation wells (Nos. 20–22, p. 268) in T. 3 N., R. 1 W., are as follows:

Log of well of Norton Bros., of Brinkley, Ark., in the SW. ¼ sec. 8, T. 4 N., R. 1 W.

[No. 20, p. 268.]

	Thickness.	Depth.
Soil and Pleistocene alluvium:	*Feet.*	*Feet.*
Soil	1.5	1.5
Clay	16.5	18
Quicksand	32	50
Fine sand	25	75
Sand, water bearing	25	100
Gravel, bowlders, water bearing	63	163
Gravel ("dead")	17	180
Eocene (?):		
Blue clay	.8	180.8

Log of well of C. E. Barber, in the S. ½ sec. 3, T. 4 N., R. 1 W.

[No. 21, p. 268.]

	Thickness.	Depth.
Soil and Pleistocene alluvium:	*Feet.*	*Feet.*
Soil	1	1
Clay	14	15
Sand and gravel, water bearing	134	149
Eocene (?):		
Blue clay	2	151

Log of well of Mr. Oliphant, 1½ miles northeast of Zent, in the W. ½ sec. 6, T. 4 N., R. 1 W.

[No. 22, p. 268.]

	Thickness.	Depth.
Pleistocene alluvium:	*Feet.*	*Feet.*
Clay	12	12
Fine sand	52	64
Coarse sand and gravel, water bearing	45	109
Coarse, bluish sand, water bearing	16	125

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Wells in St. Francis County.

	Location.				Owner.	Driller.	Authority.	Date completed.	Approximate elevation above sea level.	Depth.	Diameter.	Depth to principal water-bearing bed.	Depth to other water-bearing beds.	Water-bearing formation.
	Place.	T.	R.	Sec.										
									Feet.	*Feet.*	*Inches*	*Feet.*	*Feet.*	
1	Forrest City				St. Louis, Iron Mountain & Southern Ry. Co.		J. R. Stephens, chief engineer.			170	10			Eocene.
2	....do				....do		....do			170	10			Do.
3	....do				Town				280±	425	4	400		Wilcox formation.
4	....do				....do				280±	425+	6	400		Do.
5	....do				....do				280±	450	8	400		Do.
6	Forrest City, ½ mile east of.				Choctaw Brick Plant.				280±	600				Do.
7	Goodwin, 1½ miles west of.	4 N.	1 E.		Riley-Harrison Co.	Layne & Bowler, Stuttgart.	George Riley	1908	200±	160	11	85–160		Pleistocene alluvium.
8	Hunter (Woodruff County), 3½ miles south of.	4 N.	1 W.	5, N. ½	J. M. Brichler, Belleville, Ill.		Owner	1911	200±	160	9⅝	100–160		Do.
9	McDaniel, 1 mile east of.	4 N.	3 E.	22, NE. ¼	A. D. McDaniel	Gus Carpenter, Forrest City.	....do	1904	250±	113	2	73–113	63	Eocene?
10	Palestine	4 N.	2 E.	9, SW. ¼	J. A. Sulcer	O. S. Abels	....do			83	2	83	35	Pleistocene alluvium.
11	Wheetley				A. Boysen & Sons		A. Boysen		214±	145		80–145		Do.
12	....do	4 N.	1 W.	33, NE. ¼	Alex. Oehlschlager.	Layne & Bowler, Stuttgart.	Owner	1909	214±	142	9⅝	57–142		Do.
13	....do	4 N.	1 W.	26	C. E. Patt, Kansas City, Mo.	C. Golieke, Garden City, Kans.	E. G. Norton, Brinkley.		214±	186				Do.
14	....do				Wm. Fisher		Owner		214±	139	10	30–139		Do.
15	Zent (Monroe County), 1½ miles east of.	4 N.	1 W.	6	The Luhallis Co., Brinkley.	Arkansas Well Co., Brinkley.	J. L. Norton, Brinkley.	1910	200±	180	12	70–180		Do.
16	Zent, northeast of	4 N.	1 W.	5, SW. ¼	....do	C. Golieke, Garden City, Kans.	E. G. Norton, Brinkley.	1910	218±	175	9⅝	33–175		Do.
17	....do	4 N.	1 W.	6, SW. ¼	....do	....do	....do	1910	218±	155.6	9⅝	33–153		Do.
18	....do	4 N.	1 W.	6, SE. ¼	....do	....do	....do	1911	217±	147	9⅝	33–146		Do.
19	....do	4 N.	1 W.	6, SE. ¼	....do	....do	....do	1910	218±	462		55–145	328–378	Do.
20	Zent, east of	4 N.	1 W.	8, SW. ¼	Norton Bros., Brinkley.	....do	....do	1910	218±	180.8	9⅝	33–180		Do.
21	....do	4 N.	1 W.	3, S. ½	C. E. Barber, Wheetley.	Layne & Bowler, Stuttgart.	....do		218±	151	9⅝			Do.
22	Zent, 1½ miles northeast of.	4 N.	1 W.	6, W. ½	Mr. Oliphant	Jerome Fesperman	....do	1912	200±	125	9⅝	36–125		Do.

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	Location.				Character of principal water-bearing bed.	Level of water below surface.	Yield per minute.	Method of lift.	Cost of well.	Cost of machinery.	Use.	Quality of water.	Remarks.
	Place.	T.	R.	Sec.		*Feet.*	*Galls.*						
1	Forrest City										Boilers		Combined monthly yield, 1,200,000 gallons. Analysis 58, p. 302.
2	do										do		
3	do				Coarse sand	70	100+				Municipal supply.		The three wells operated in combination are the source of the municipal water supply.
4	do				do	70	100+				do		
5	do				do	70	100+				do		
6	Forrest City, ¼ mile east of.										Boilers		
7	Goodwin, 1½ miles west of.	4 N.	1 E.		Gravel	4	2,500		$3,500		Irrigation		Analysis 59, p. 302.
8	Hunter (Woodruff County), 3½ miles south of.	4 N.	1 W.	5, N. ½	do	27	2,500	Steam			Domestic and irrigation.		
9	McDaniel, 1 mile east of.	4 N.	3 E.	22, NE. ¼	Fine sand	36		Wind.	75	206	Domestic	Medium soft	
10	Palestine	4 N.	2 E.	9, SW. ¼	Gravel	20		Hand.	50		do	Hard	
11	Wheetley				do	30	1,500	Steam	1,500	500	Domestic and irrigation.		There are 8 similar wells on this property used for irrigating rice fields. Analysis 61, p. 302.
12	do	4 N.	1 W.	33, NE. ¼	do	32	1,200	do	2,000		Irrigation	Hard	85 feet of 9½-inch casing and 57 feet of 9½-inch strainer.
13	do	4 N.	1 W.	26	Sand and gravel			do			do		
14	do				Quicksand	30	1,500	do	1,750		do		Analysis 60, p. 302.
15	Zent (Monroe County), 1¼ miles east of.	4 N.	1 W.	6	Sand and gravel	30	2,000	do	2,500		do		70 feet of 24-inch casing and 110 feet of 12-inch casing and screen. Analysis 63, p. 302.
16	Zent, northeast of	4 N.	1 W.	5, SW. ¼	do	33	1,100	do	1,800	700	do	Alkaline	70 feet of 24-inch steel pit and 105 feet of 9½-inch casing and screen.
17	do	4 N.	1 W.	6, SW. ¼	Sand	33	600	do	1,800	700	do	do	50 feet of 24-inch steel pit and 105.6 feet of 9½-inch casing and screen.
18	do	4 N.	1 W.	6, SE. ¼	Sand and gravel	33	2,500	do	1,800	700	do	do	70 feet of 24-inch steel pit and 77 feet of 9½-inch casing and screen.
19	do	4 N.	1 W.	6, SE. ¼	Fine sand	33						do	Drilled as a test well.
20	Zent, east of	4 N.	1 W.	8, SW. ¼	Sand and gravel	33	1,100	Steam.	1,800	700	Irrigation		54 feet of 24-inch steel pit and 126.8 feet of 9½-inch casing and screen. Analysis 62, p. 302.
21	do	4 N.	1 W.	3, S. ½	do		2,000	do			do		
22	Zent, 1½ miles northeast of.	4 N.	1 W.	6, W. ½	do	36		do			do		

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WHITE COUNTY.

PHYSIOGRAPHY.

White County, in the northeast-central part of the State, comprises an area of 1,037 square miles. Its population at the time of the census of 1910 was 28,574. The principal industry is agriculture, the products including cotton, cereals, vegetables, and hay.

The county is topographically divisible into two parts. The part west of a line running northeast-southwest a few miles west of the St. Louis, Iron Mountain & Southern Railway is the Ozark province, a strongly dissected upland lying 400 to 1,000 feet or more above sea level and containing about three-fifths of the total area of the county. The remainder of the county is included in the Gulf Coastal Plain, the greater part of which is a nearly level or gently rolling plain known as the Advance lowland, lying 215 to 230 feet above sea level. Only that part of the county lying east of the Ozark province is treated in this report.

Along the western margin of the Coastal Plain in the northern part of the county bordering the Ozark province is a narrow terrace or ridge more or less clearly defined, forming the southern extremity of the Grandglaise terrace, the crest of which is 250 to 300 feet above sea level, or 40 to 50 feet above the lowland to the east. Bordering the Ozark province, southwest of Beebe in the southern part of the county, there is also a small hilly tract, which rises somewhat above the level of the Advance lowland.

White River forms the eastern boundary of the county. Little Red River leaves the Ozark province near Searcy, flows a little south of east, and joins White River about 6 miles north of the southeastern corner of the county. Bayou des Arc, a tributary of White River, forms the greater part of the southern boundary. The broad flood plains of these streams are heavily timbered, and swamps, bayous, and abandoned stream channels are numerous. The interstream areas are gently rolling and are for the most part timbered except where cleared for cultivation. There are a few patches of prairie land in the southern part of the county.

GEOLOGY.

The Ozark province is underlain by undifferentiated Paleozoic sandstones and shales of Pennsylvanian age. They are separated from the deposits of the Coastal Plain on the east by a relatively steep, eastward-facing erosion escarpment along the line of which the older rocks pass under the deposits of the Coastal Plain and extend eastward beneath them, lying deeper in that direction. The Paleozoic rocks have been reached in wells east of the escarpment at a few places along the St. Louis, Iron Mountain & Southern Railway. (See records of wells, p. 272.)

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The deposits of the Coastal Plain are of Cretaceous, Tertiary, and Quaternary age. So far as known Cretaceous strata do not outcrop within the county, but marl containing characteristic Cretaceous fossils has been taken from a well at Beebe between the depths 29 and 64 feet.[1] Strata of this age are believed to underlie all the Coastal Plain portion of the county. They rest upon the rocks of the Paleozoic basement and are overlain by Eocene and younger deposits.

Marls and limestone belonging to the Midway formation of the Eocene outcrop at a few places in the Grandglaise terrace and marls, probably of Midway age, have been recognized in well borings near Beebe. Undifferentiated strata of Eocene age are believed to make up the body of some low hills southwest of Beebe. East of the Grandglaise terrace in the Advance lowland undifferentiated strata of Eocene age are believed to be present, resting upon the deeply buried Cretaceous strata and overlain by 100 to 150 feet of Quaternary alluvial deposits. Both the Eocene and underlying Cretaceous deposits probably contain important water-bearing beds.

The Quaternary alluvium, which immediately underlies the Advance lowland to estimated depths of 100 to 150 feet, is of Pleistocene and Recent age. The Pleistocene deposits, though irregularly bedded, in general grade downward from fine silty clays or sands at the surface through fine sands to coarse abundantly water-bearing sands and gravels at the base. They rest unconformably upon Paleozoic, Cretaceous, and Eocene strata and outcrop in the interstream areas. Recent loams, clays, sands, and gravels compose the flood-plain deposits of the present streams.

WATER RESOURCES.

GENERAL CONDITIONS.

In the Coastal Plain area water for domestic and industrial uses is obtained chiefly from wells 15 to 80 feet deep. In the Advance lowland wells that yield sufficient water for ordinary domestic supplies tap the water-bearing sands and gravels of the Quaternary alluvial deposits, and in the Grandglaise terrace beds belonging to the Midway formation are the source of supply. The waters stand in the wells 10 to 50 feet below the surface and, according to the reports of well owners, many are hard, some are soft, and some are ferruginous. In a considerable area in the eastern part of the county, particularly in the vicinity of West Point, Worden, and east of Russell, waters having a distinct brackish taste, probably due to common salt, are obtained.

Small springs which emerge from strata of the Midway formation are numerous along the narrow ridge or terrace known as the

[1] Harris, G. D., The Tertiary geology of southern Arkansas: Arkansas Geol. Survey Ann. Rept., vol. 2, pp. 10, 11, 1892.

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Grandglaise terrace, and are utilized to some extent for domestic supplies.

The undifferentiated Cretaceous and Eocene deposits which intervene between the Quaternary alluvium and the Paleozoic basement rocks are believed to contain important water-bearing beds that would be reached by wells ranging in depth from 150 to 200 feet near the western part of the area to a maximum of 800 or 1,000 feet in the extreme southeastern part. These waters are under hydrostatic pressure probably sufficient to bring them within 50 feet or less of the surface.

LOCAL SUPPLIES.

Bald Knob.—At Bald Knob (population 617, census of 1910) the St. Louis, Iron Mountain & Southern Railway Co. obtains water for locomotives from a well 225 feet deep (No. 1, p. 273), which enters Paleozoic rocks at a depth of 31 feet; the water, which rises within 38 feet of the surface, comes from a crevice in these rocks at a depth of 193 feet. The well yields 4,000,000 gallons a month. When pumped at the rate of 5,000 gallons an hour the static head is reduced 4 feet and 5 inches. (See analysis 64, p. 302.)

The following is a log of the well:

Log of well of the St. Louis, Iron Mountain & Southern Railway, Bald Knob.

	Thickness.	Depth.
	Feet.	*Feet.*
Quaternary alluvium:		
Yellow clay	30	30
Sand and gravel	1	31
Paleozoic:		
Hard rock	30	61
Soft blue rock	9	70
Hard rock	70	140
Soft black rock	12	152
Hard rock; at a depth of 193 feet a crevice was struck, which is believed to furnish the principal water supply	73	225

Higginson.—The St. Louis, Iron Mountain & Southern Railway Co. owns two wells at Higginson (population 192, census of 1910), each 62.5 feet deep (Nos. 2 and 3, p. 273). They tap the coarse sands and gravels at the base of the Quaternary alluvium and yield at the rate of 3,500,000 gallons a month. An analysis of the mixed water from the two wells is given in the table opposite page 302 (No. 65). The following is a log of one of the wells:

Log of well of the St. Louis, Iron Mountain & Southern Railway, Higginson.

	Thickness.	Depth.
	Feet.	*Feet.*
Quaternary alluvium:		
Clay	30	30
Fine sand	20	50
Coarse sand with pebbles and cobbles, water bearing; stopped drilling on rock	12.5	62.5

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Wells in White County.

	Location.				Owner.	Driller.	Authority.	Date completed.	Approximate elevation above sea level.	Depth.	Diameter.	Depth to principal water-bearing bed.	Depth to other water-bearing beds.	Geologic name of water-bearing formation.
	Place.	T.	R.	Sec.										
									Feet.	*Feet.*	*In.*	*Feet.*	*Feet.*	
1	Bald Knob				St. Louis, Iron Mountain & Southern Ry. Co.		J. R. Stephens, chief engineer.		231	225	6	193		Carboniferous.
2	Higginson				do		do		226±	62.5	10	50–62.5		Pleistocene alluvium.
3	do				do		do		226±	62.5	10	50–62.5		Do.
4	Kensett				Kensett Ice Co		H. E. Watson		230±	63		60	34	Quaternary alluvium.
5	Kensett, 1½ miles north of.	7 N.	6 W.	8, NW. ¼	Doniphar Lumber Co.	Thos. F. Hughes	H. Kilpatrick	1910	230±	165	7			Pleistocene alluvium.
6	Kensett				Geo. F. Meyer		Owner	1911	230±	50	1½	50	35	Quaternary alluvium.
7	West Point	7 N.	6 W.	26, NE. ¼	S. N. Wright	Owner	do	1911		76	2	72		Pleistocene alluvium.
8	do	7 N.	6 W.	25, SW. ¼	M. B. Johnson	C. K. Williams	do	1902		60	12	55		Do.
9	Worden	8 N.	5 W.	25, NW. ¼	W. H. Davidson		do	1901	216±	60	1½	35		Do.
10	Worden, ½ mile west of	8 N.	5 W.	25	O. R. Root		do	1907	216±	58	1½	45–58		Do.

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WOODRUFF COUNTY.

PHYSIOGRAPHY.

Woodruff County, in the northeast-central part of the State, embraces an area of 577 square miles. The census of 1910 reported its population to be 20,049. Agriculture is the chief industry, the principal crops being cotton, corn, rice, and hay.

The county is included in the topographic subdivision of the Gulf Coastal Plain known as the Advance lowland, the surface of which is in general a gently undulating plain 190 to 235 feet above sea level and sloping slightly to the south. White River forms the western boundary; Cache River enters the county in the north and flows a little west of south entirely across the county. The area between White and Cache rivers is heavily timbered and is nearly all included in the flood plain of the two streams; it is characterized by swamps, bayous, and lakes, separated by low ridges of sand or sandy loam. Bayou De Vue enters the county in the northeastern corner and flows a little west of south to the southern boundary. Between Cache River and Bayou De Vue and 15 or 20 feet higher than the flood plain to the west is a belt of land locally known as Nubbin Ridge, which has been largely cleared for cultivation. East of Bayou De Vue the surface presents irregular patches of grass-covered prairie separated by tracts of slightly depressed timbered lands.

GEOLOGY.

Quaternary alluvium of Pleistocene and Recent age underlies the surface to depths estimated at 125 to 165 feet. The Pleistocene deposits rest unconformably upon Eocene strata and outcrop in the higher interstream areas in the eastern half of the county and to a small extent in the northern part of the county. Although irregularly bedded they grade downward in general from fine silty loams or clays at the surface, through fine sands to coarse water-bearing sands and gravels at the base. Recent alluvial loams, clays, sands, and gravels underlie the flood plains of the present streams to an undetermined depth.

The Eocene strata which underlie the Quaternary alluvium are probably several hundred feet thick and are in turn underlain by Cretaceous deposits which, at a depth of 900 to 1,200 feet or more, rest upon Paleozoic basement rocks. The only definite information available concerning the character of the undifferentiated Eocene and Cretaceous strata is furnished by a 900-foot well at Augusta, which is reported to have penetrated "dry" blue clay from a depth of 145 feet to a depth of 900 feet, where hard rock, probably Paleozoic basement rock, was struck.

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WATER RESOURCES.

GENERAL CONDITIONS.

Water for domestic, industrial, and irrigation supplies is obtained chiefly from wells 10 to 165 feet deep which tap the abundantly water-bearing sands and gravels of the Quaternary alluvium. The water stands in the wells a few feet to 40 feet below the surface, and, according to the reports of the well owners, most of the waters are soft but a few are hard.

Although the 900-foot well at Augusta is reported to have encountered only non water-bearing clays from a depth of 145 to 900 feet, it is believed that this condition, if accurately reported, is of local extent and that elsewhere the prospects are good for obtaining water from interbedded sandy layers in these undifferentiated Eocene and Cretaceous deposits. Such waters would be under hydrostatic pressure which would probably bring them within less than 50 feet of the surface.

LOCAL SUPPLIES.

Augusta.—The municipal water supply of Augusta (population 1,520, census of 1910), the county seat, is owned by Campbell & Vinson. The water is obtained from two wells, 100 feet deep (Nos. 1 and 2, p. 278), whose combined daily yield is 200,000 gallons. A Cook strainer is inserted in the lower 20 feet of each well. The water is distributed at a pressure of 40 pounds per square inch from a standpipe holding 50,000 gallons. The level of the water in the wells is said to fluctuate with the level of White River, the maximum range being from 20 to 40 feet below the surface. The water is strongly ferruginous.

The following log of a 900-foot well drilled at Augusta some time ago is based on the oral statements of citizens, and the character and thickness of the strata are therefore given only approximately.

Log of 900-foot well at Augusta.

[No. 3, p. 278.]

	Thickness.	Depth.
Quaternary alluvium:	*Feet.*	*Feet.*
Yellow clay loam	30	30
Sand, water bearing	70	100
Not reported	45	145
Undifferentiated Eocene and Cretaceous:		
"Dry" blue clay; stopped drilling on hard rock	755	900

Cotton Plant.—The municipal water supply of Cotton Plant (population 1,081, census of 1910), information concerning which has been furnished by F. H. Kennedy, postmaster, is obtained from

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a shallow well 36 (?) feet deep and is distributed from a 50,000-gallon tank.. The water is soft and the daily consumption is 15,000 gallons.

Wells for irrigation.—Rice is grown on the prairies in the eastern part of the county and water for irrigation is obtained from wells 100 to 160 feet deep, yielding 1,500 to 2,500 gallons a minute. Detailed information concerning five irrigation wells is given in the table on page 278 (Nos. 7–11). The logs of three of these wells follow:

Log of well of the Hunter Land & Rice Co., near Hunter.

[No. 8, p. 278.]

	Thickness.	Depth.
Soil and Pleistocene alluvium:	*Feet.*	*Feet.*
Soil	1.25	1.25
Clay	.75	2
"Hardpan"	16	18
Quicksand	22	40
Fine sand, water bearing	30	70
Coarse sand, water bearing	20	90
Gravel and bowlders, water bearing; stopped on blue clay, probably of Eocene age	37	127

The driller states that gas was encountered in this well with pressure sufficient to lift the tools 4 inches.

Log of well No. 2 of the Hunter Land & Rice Co., near Hunter.

[No. 7, p. 278.]

	Thickness.	Depth.
Soil and Pleistocene alluvium:	*Feet.*	*Feet.*
Soil	1.5	1.5
Clay	1	2.5
"Hardpan"	14.5	17
Quicksand	33	50
Fine sand, water bearing	30	80
Coarse sand, water bearing	20	100
Gravel and bowlders, water bearing	55	155
Eocene (?):		
Blue clay	1	156

Log of well of H. L. Baker, 1¾ miles southwest of Hunter.

[No. 9, p. 278.]

	Thickness.	Depth.
Soil and Pleistocene alluvium:	*Feet.*	*Feet.*
Soil	3	3
Bluish-white clay	12	15
Quicksand	8	23
Character not stated but the materials are slightly water bearing	42	65
Fine gravel, water bearing	9	74
Coarser gravel, water bearing	16	90
Sand and gravel, water bearing	18	108

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Wells in Woodruff County.

	Location.				Owner.	Driller.	Authority.	Date completed.	Approximate elevation above sea level.	Depth.	Diameter.	Depth to principal water-bearing bed.	Depth to other water-bearing beds.	Geologic name of water-bearing formation.
	Place.	T.	R.	Sec.										
									Feet.	*Feet.*	*Inches*	*Feet.*	*Feet.*	
1	Augusta	.....	.....	.....	Augusta Waterworks Co.	.....	.....	1903	.....	100	6	.....	.....	Quaternary alluvium.
2	.....do	.....	.....	.....	.....do	.....	.....	1903	.....	100	6	.....	.....	Do.
3	.....do	.....	.....	.....	.....	.....	.....	.....	.....	900	.....	.....	.....	.....
4	Hilleman	6 N.	1 W.	22, SE. ¼	Geo. Hillemann, Altamont, Ill.	.....	J. L. Stair	1907	210±	60±	2½	30–60±	.....	Pleistocene alluvium.
5	Howell	6 N.	2 W.	30, NW. ¼	T. A. Smith	.....	Owner	1890	216±	76	1½	76	47.5	Do.
6	.....do	6 N.	2 W.	30, NE. ¼	Town	John Jacobs, Judsonia.	R. T. Martin	1905	216±	80	1½	45–80	.....	Do.
7	Hunter, southeast of	5 N.	1 W.	34	Hunter Land & Rice Co. (well No. 2).	C. Golieke, Garden City, Kans.	E. G. Norton, Brinkley.	.....	212±	156	.....	50–105	.....	Do.
8	.....do	5 N.	1 W.	34	Hunter Land & Rice Co. (well No. 1).	.....do	.....do	.....	212±	127	.....	40–127	.....	Do.
9	Hunter, 1¾ miles southeast of.	5 N.	1 W.	21	H. L. Baker	Oscar Lowe, Jennings, La.	Owner	1910	212±	108	12	75–108	23–48	Do.
10	Hunter, 3 miles south of	5 N.	1 W.	30, SW. ¼	I. N. Strickler	.....	.....do	1906	210±	115	8	30–115	.....	Do.
11	Penrose	7 N.	1 W.	25, SE. ¼	McCleery & Son	Walters & Baker, Hunter.	R. W. McCleery.	1911	215±	124	10	60–124	.....	Do.

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	Location.				Character of principal water-bearing bed.	Level of water below surface.	Yield per minute.	Method of lift.	Cost of well.	Cost of machinery.	Use.	Quality of water.	Remarks.
	Place.	T.	R.	Sec.									
						Feet.	*Galls.*						
1	Augusta					20–40	70				Municipal supply.	Ferruginous...	
2	....do					20–40	70					....do	
3	....do												Hard rock (Paleozoic ?) struck at 900 feet.
4	Hilleman	6 N.	1 W.	22, SE. ¼..	Sand	20		Steam.			Boilers	Alkaline	
5	Howell	6 N.	2 W.	30, NW. ¼..	....do	28		Hand.	$45		Domestic	Soft	
6	....do	6 N.	2 W.	30, NE. ¼..	Gravel	40	2	...do..	80		....do	....do	
7	Hunter, southeast of.	5 N.	1 W.	34	Sand and gravel						Irrigation		Analysis 66, p. 302.
8	....do	5 N.	1 W.	34	....do						....do		Analysis 67, p. 302.
9	Hunter, 1¾ miles southeast of.	5 N.	1 W.	21	Coarse gravel	23	1,600	Steam.	1,100	625	....do		Pit 50 feet deep, 18 feet of 12-inch casing and 40 feet of 12-inch screen.
10	Hunter, 3 miles south of.	5 N.	1 W.	30, SW. ¼..	Sand	30	2,500	...do ..	1,000	200	Domestic and irrigation.		
11	Penrose	7 N.	1 W.	25, SE. ¼..	Gravel	19	2,000		1,000		....do		Analysis 68, p. 302.

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CHEMICAL CHARACTER OF THE WATERS OF NORTHEASTERN ARKANSAS.

By R. B. Dole.

STANDARDS OF CLASSIFICATION.

MINERAL CONSTITUENTS OF WATER.

The substances that may be present in natural waters are classified for analysis as suspended matter, such as particles of clay or leaves; dissolved matter, either of mineral or organic origin; microscopic animals or plants; and bacteria. The presence of very small animals and plants likely to affect the quality of waters is determined by microscopic examination, and the chance of contracting disease by drinking the water is studied by bacteriologic processes. The amount and nature of the mineral ingredients are most commonly determined by estimating the total suspended matter, total dissolved matter, total hardness, total alkalinity, silica, iron, aluminum, calcium, magnesium, sodium, potassium, carbonate, bicarbonate, sulphate, nitrate, chloride, free carbon dioxide, and free hydrogen sulphide. These estimates are a measure of the materials most commonly present and most likely to affect the value of the waters.

WATER FOR BOILER USE.

FORMATION OF SCALE.

The most common trouble in boilers is formation of scale, for when the water is heated under pressure and concentrated certain substances are thrown out of solution and form an incrustation on the flues or crown sheets or within the tubes. This scale or incrustation includes practically all the suspended matter or mud; the silica, probably precipitated as the oxide (SiO_2); the iron and aluminum, appearing in the scale as oxides or hydrated oxides; the calcium, precipitated principally in the form of carbonate and sulphate; and the magnesium, found in the deposits principally as the oxide but partly as the carbonate. The scale is therefore a mixture, which

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varies in amount, density, hardness, and composition with different conditions of water supply, steam pressure, type of boiler, and other circumstances. Calcium and magnesium are the principal basic substances in the scale, over 90 per cent of which usually is calcium, magnesium, carbonate, and sulphate. If much organic matter is present, part of it is precipitated with the mineral scale, as the organic matter is decomposed by heat or by reaction with other substances. If magnesium and sulphate are comparatively low, or if suspended matter is comparatively high, the scale is soft and bulky and may be in the form of sludge that can be blown or washed from the boiler. On the other hand, a clear water relatively high in magnesium and sulphate may produce a hard, compact scale that is nearly as dense as porcelain, clings to the tubes, and offers great resistance to the transmission of heat.

CORROSION.

Corrosion or "pitting" is caused chiefly by the solvent action of acids on the iron of the boiler. Organic matter is probably a source of acids, for it is well known that waters high in organic matter and low in calcium and magnesium are corrosive, though the exact nature and the action of the organic bodies are not well understood. Acids freed in the boiler by the deposition of iron, aluminum, and magnesium as hydrates are the chief cause of corrosion, and magnesium deserves particular attention, as it is the most abundant of the three. The acid radicles that were in equilibrium with these bases may do one or all of three things, according to the chemical composition of the water: They may pass into equilibrium with other bases, displacing equivalent quantities of carbonate and bicarbonate; they may decompose carbonate that has been precipitated as scale; or they may combine with the iron of the boiler, thus causing corrosion. Which of these reactions will occur can be expressed even with the most complete analyses only as a probability. If the acid thus freed exceeds the amount required to decompose the carbonate and bicarbonate, the iron of the boiler is attacked and pits or tuberculations of the interior surface, leaks, particularly around rivets, and consequent deterioration of the boiler result.

FOAMING.

Foaming is the formation of masses of bubbles on the surface of the water in the boiler and in the steam space above the water, and it is intimately connected with priming, which is the passage from the boiler of water mixed with steam. The principal cause of foaming is usually believed to be an excess of dissolved matter; conse-

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quently, as sodium and potassium remain dissolved in the boiler water while the greater portion of the other bases is precipitated, the foaming tendency is commonly measured by the degree of concentration of the alkaline salts in solution, because this figure, in connection with the type of boiler, determines to great extent the length of time that a boiler may run without danger of foaming. It is a fact that the worst foaming waters in railroad practice are encountered in the arid and semiarid regions of the Southwest, where the quantity of dissolved alkali is greatest. However, it is well known that suspended matter can cause foaming, for certain surface waters that when clear do not foam, but deposit a moderate amount of scale, foam badly whenever they carry a great quantity of mud. The design of the boiler, irregular blowing off, neglect to change water periodically, introduction of oil into the feed water from the exhaust steam, and improper firing and feeding are doubtless factors in foaming.

REMEDIES FOR BOILER TROUBLES.

It is best to treat feed waters before they enter boilers, but when such treatment can not be given there are various ways of obviating trouble. Low-pressure, large-flue boilers are frequently used in many stationary plants with hard waters, and it is said that the scale formed in them is softer and more flocculent and can therefore be more readily removed than that in high-pressure boilers. Blowing off is about the only practical means of preventing foaming, because this trouble is due principally to concentration of substances in the residual water of the boilers. Accumulated sludge, or soft scale, is removed by blowing, particularly in locomotive practice.

BOILER COMPOUNDS.

Boiler compounds are widely used in regions where hard waters abound, but treatment within the boiler should be given only when it is impossible to purify the supply before it enters the boiler or when the relatively pure condition of the supply requires only minor correction. If previous purification is not practicable, some feed waters can be improved by judicious addition of chemicals. Though many substances have been recommended for such use, only a few have proved to be really efficient. Soda ash, the commercial form of sodium carbonate, containing about 95 per cent Na_2CO_3, is most valuable for attacking chemically the scaling and corroding constituents, precipitating the incrusting matter, and neutralizing acids because it is cheap and its use is attended with the least objectionable results. The proper amount of it to be used depends on the

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chemical composition of the water and the type of boiler. Tannin and tannin compounds are also used for the same purpose. The addition of limewater to some feed waters high in organic matter and free carbon dioxide and very low in incrustants effectively prevents corrosion and foaming. Certain other boiler compounds act mechanically on the precipitated crystals of scale-making matter soon after they are formed, surrounding them and robbing them of their cement-like action. Glutinous, starchy, and oily substances belong to this class, but they are not now used to any considerable extent because they thicken and foul the water more than they prevent the formation of hard scale. Kerosene is effective in partly dissolving deposited scale, thus loosening it and permitting its ready removal, and graphite is extensively used to prevent formation of hard scale and sticking of particles to the boiler tubes or shell.

Many boiler compounds possessing or supposed to possess one or more of the functions just described are on the market and are widely sold. Some are effective and some are positively injurious. Most of them depend for their chief action on soda ash, petroleum, or a vegetable extract, but all are costly compared with lime and soda ash. Boiler compounds can not reduce the amount of scale, but may increase it. Their only legitimate functions are to prevent corrosion and deposition of hard scale and to remove accumulations of scale that have become attached to the boiler. Every engineer should bear in mind that a steam boiler is an expensive piece of apparatus and that fuel and boiler repairs also are expensive. Therefore he should hesitate to add substances to his feed water without competent advice regarding their effect. It is far more economical to have the water supply analyzed and to treat it effectively by well-known chemicals in proper proportion, either within or without the boiler, than to experiment with compounds of unknown composition.

NUMERICAL STANDARDS.

The probable quantities of scale-forming and foaming ingredients and the probability of corrosion when the waters are used in boilers have been computed for the analyses published in this report by means of modifications of certain formulas published in Stabler's excellent discussion[1] of the quality of mineral waters. His terms involving iron, aluminum, and free acids have been omitted because the amount of these substances in the waters of Arkansas is usually too small to necessitate consideration in such approximate rating; the terms involving sodium and potassium have been united for sim-

[1] Stabler, Herman, The mineral analysis of water for industrial purposes and its interpretation by the engineer: Eng. News, vol. 60, p. 355, 1908; also U. S. Geol. Survey Water-Supply Paper 274, p. 165, 1911.

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plicity. The coefficients have been recomputed to give the estimates in parts per million.

(1) $s = Sm + Cm + 2.95\ Ca + 1.66\ Mg$.
(2) $h = SiO_2 + 1.66\ Mg + 1.92\ Cl + 1.42\ SO_4 - 2.95\ Na$.
(3) $f = 2.7\ Na$.
(4) $c = 0.0821\ Mg - 0.333\ CO_3 - 0.0164\ HCO_3$.

These equations express numerically some of the relations that have been discussed in the preceding sections on scale, corrosion, and priming. Sm, Cm, SiO_2, Ca, Mg, Na, Cl, SO_4, CO_3, and HCO_3 represent the amounts in parts per million, respectively, of suspended matter, colloidal matter (oxides of silicon, iron, and aluminum), silica, calcium, magnesium, alkalies, chlorine, sulphate, carbonate, and bicarbonate. The first formula gives the amount of scale-forming ingredients (s) under ordinary conditions of boiler operation. As values for silica (SiO_2) are given in only a few of the analyses in this report, 35 has been taken as a fair average value for that substance in computing the value of s. Fortunately, silica is a relatively constant ingredient, its values ranging within comparatively narrow limits irrespective of the abundance of other ingredients. As most of the ground waters of Arkansas carry practically no suspended matter, Sm generally has the value of zero, but the term can not be disregarded in estimating the value of raw surface waters, which frequently contain more suspended than dissolved matter.

The hard-scale-forming ingredients (h) may be estimated by formula 3; therefore the ratio, $\frac{h}{s}$, expresses the relative hardness of the scale. If $\frac{h}{s}$ is greater than 0.5 the scale may properly be called hard; if it is less than 0.25 the scale may be called soft. The third formula gives an estimate of the foaming ingredients (f) based on the probable amount of alkali salts dissolved in the water.

Formula 4 has been used to calculate the corrosive tendency of the water (c), and it can be readily seen from the coefficients that it expresses the relation between the reacting values of magnesium and the radicles involving carbonic acid outlined in the discussion of corrosion. If c is positive the water is corrosive. If $c + 0.0499$ Ca, the reacting value of calcium, is negative, corrosion due to the mineral constituents will not take place; whether organic matter or electrolysis can then cause corrosion is uncertain. If $c + 0.0499$ Ca is positive the probability of corrosion is uncertain.

After these three attributes of boiler feed have been computed it is largely a matter of judgment based on experience to rate the water. The value of natural waters for use in boilers depends primarily on their corroding and foaming tendencies and on the amount and

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character of scale likely to be deposited by them, but this value should always be considered in connection with local standards, for no matter how low a water may be in undesirable constituents it can not be classed as good if it is poorer in quality than the average water of the region in which it occurs, and, on the other hand, if the best available supply is poor the economy of purifying it, even at large expense, is obvious.

Waters of poor quality can be improved by treatment in softening plants. The question how bad a water may be used without treatment can be answered by comparing the cost of artificially softening the water with the saving effected by the use of softened water. The benefits of softening include saving in boiler cleaning, in repairs, and in fuel, increased number of boilers in service, decreased depreciation of boilers, and the value of the materials removed by softening. The cost of softening includes labor and power for the softening apparatus, value of softening chemicals, interest on cost of installation, depreciation in value of softening plant, and waste in changing boiler feed due to increased foaming tendency. In general, it is economical in locomotive service to treat waters containing 250 to 850 parts per million of incrustants and those containing less than the lower amount if the scale formed contains much sulphate.[1]

The amount of mineral matter that makes a water absolutely unfit for boiler use depends on the combined effect in boilers of the softening reagents used with such waters and of the constituents not removed by softening. Sodium salts added to remove incrustants or to prevent corrosion increase the foaming tendency and this increase may be great enough to render a water useless for steaming. It is not of much benefit to soften a water containing more than 850 parts per million of nonincrusting material and much incrusting sulphate.[1] Though waters containing as high as 1,700 parts per million of foaming constituents have been used in locomotives, it is usually more economical to incur considerable expense in replacing such supplies by better ones. A concentration of about 7,000 parts is considered the limit of safety for stationary boilers.

The ratings of the committee on water service of the American Railway Engineering and Maintenance of Way Association given in the following table have been used for classifying the Arkansas waters in respect to boiler use. These limits are obviously only approximate and the classifications must therefore not be taken too literally. They are given rather to indicate the limits of usefulness than to define rigidly the value of the waters.

[1] Am. Ry. Eng. and Maintenance of Way Assoc. Proc., vol. 6, p. 610, 1905.

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Rating of waters for boiler use according to proportion of incrusting and corroding constituents and according to proportion of foaming constituents.

Incrusting and corroding constituents (parts per million).			Foaming constituents (parts per million).		
More than—	Not more than—	Classification.[a]	More than—	Not more than—	Classification.[b]
.....	90	Good.	.....	150	Good.
90	200	Fair.	150	250	Fair.
200	430	Poor.	250	400	Bad.
430	680	Bad.	400	.....	Very bad.

[a] Am. Ry. Eng. and Maintenance of Way Assoc. Proc., vol. 5, p. 595, 1904.
[b] Idem, vol. 9, p. 134, 1908.

WATER FOR IRRIGATION.

RELATION BETWEEN APPLIED WATER AND SOILS.

When water evaporates from the surface of soil it leaves its content of salts. If all the water applied in irrigating were to evaporate, the constant use of any supply, no matter how good it might be, would eventually result in an accumulation of alkali that would render the soil unproductive. If, on the other hand, all of a water not too high in mineral content were to seep downward into the deep-lying strata it would gradually leach out the soluble salts of a highly charged area. Such extreme conditions, however, are not normal, for seepage from irrigated tracts carries with it a load of dissolved salts; various amounts of mineral matter are also taken up by crops and are removed during harvesting; then, too, proper methods of irrigation and drainage will prevent alkali from accumulating where it will damage the delicate feeding roots of crops. Consequently, waters of relatively low mineral content may be applied year after year without inflicting damage, but those exceeding a certain limit of mineral content are useless for irrigation; waters of an intermediate class, normally capable of increasing the alkali in the soil, may be harmless under judicious usage.

NUMERICAL STANDARDS.

The value of a water for irrigation is measured primarily by its content of alkali and by the probable form in which the alkali will be deposited in the soil. Experience has shown that sodium carbonate is most harmful to crops, sodium chloride less so, and sodium sulphate least harmful of all. Basing his computations on determinations of the alkali-resisting qualities of certain cultures in

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California,[1] Stabler has developed formulas[2] for rating waters in respect to their value for irrigation. His comparison is made by means of an "alkali coefficient" (k), which is defined as the depth in inches of water which would yield on evaporation sufficient alkali to render a 4-foot depth of soil injurious to the most sensitive crops. The sodium equivalents of the three common salts of sodium, the sulphate, chloride, and carbonate, are assigned relative toxicities of 1, 5, and 10, respectively, and the maximum tolerance of sensitive cultures is taken as 1,500 pounds of sodium in the form of sulphate per acre-4-feet. The correctness of the latter assumption by itself might be questioned, but it does not lead to appreciable error, as the chief value of the formulas rests with the ratio of toxicities and the interpretation of the computed value of k.

$$k = \frac{2{,}040}{\text{Cl}} \text{ if Na} - 0.65\ \text{Cl is zero or negative.}$$

$$k = \frac{6{,}620}{\text{Na} + 2.6\,\text{Cl}} \text{ if Na} - 0.65\ \text{Cl is positive but not greater than } 0.48\ \text{SO}_4.$$

$$k = \frac{662}{\text{Na} - 0.33\,\text{Cl} - 0.43\,\text{SO}_4} \text{ if Na} - 0.65\ \text{Cl} - 0.48\ \text{SO}_4 \text{ is positive.}$$

The symbols SO_4, Cl, and Na represent, respectively, the amounts in parts per million in the water of sulphate, chlorine, and alkali, the latter being commonly grouped under the name of sodium. The three formulas represent the different relations between the alkali and the acid radicles. Under the first condition, with enough or more than enough chlorine to satisfy sodium, it is assumed that the chlorides other than that of sodium are as harmful as that compound. Under the second condition, where the chloride and sulphate radicles together are sufficient to satisfy sodium, and under the third, where both chlorine and sulphate are insufficient to satisfy sodium, magnesium is assumed to have no deleterious effect. This base loses the greater part of its toxic power when much calcium is present and therefore this assumption seems justifiable, as not only is calcium usually high in all soils, but also it commonly exceeds the proportion of magnesium in natural waters. Though the formulas are based on the relative predominance of the radicles they should not be interpreted as signifying that the acids and bases are combined but as presenting the maximum possibilities of the deposition of harmful alkali salts in the soil layer.

[1] Loughridge, R. H., Tolerance of alkali by various cultures: California Univ. Agr. Exp. Sta. Bull. 133, 1901. Quoted by E. W. Hilgard, Soils, p. 467, Macmillan Co., New York, 1906. See also California Univ. Agr. Exp. Sta. Bulls. 128, 140, and 169.

[2] Stabler, Herman, Some stream waters of the western United States, with chapters on sediment carried by the Rio Grande and the industrial application of water analyses: U. S. Geol. Survey Water-Supply Paper 174, p. 177, 1911; also Eng. News, vol. 64, p. 57, 1910.

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The following ratings for interpreting values of the alkali coefficient are proposed by Stabler:

Classification of water for irrigation.

Value of *k*.	Classification.
Greater than 18	Good.
6 to 18	Fair.
1.2 to 5.9	Poor.
Less than 1.2	Bad.

The value of *k*, showing the number of inches of water that would yield on evaporation sufficient alkali to inhibit the growth of very sensitive plants, indicates the relative degree of care that is essential in applying a water to irrigated tracts. As defined by Stabler, "good" waters are those that can be used for many years without special care to prevent alkali accumulation. Waters classed as "fair" require special care to prevent gradual concentration of alkali, except in loose soils with free natural drainage. Care in selection of soils has been imperative and artificial drainage has frequently been necessary in using waters classed as "poor." The "bad" waters contain so much harmful matter in solution that they are practically valueless for irrigation.

This rating, like any other that might be devised, should be liberally interpreted. It signifies only a comparison of the waters themselves on the basis of their mineral content. It does not signify the possibility of raising good crops on land to which the waters may be applied, because it does not take into account the alkali content and the texture of the soil, conditions of drainage, the method of irrigation, the duty of the water, or the other factors on which agricultural success depends. As the rating is based on common irrigation practice in the arid and semiarid regions of the United States, it is probably too severe for a well-watered region like eastern Arkansas; therefore, it may safely be concluded that waters of eastern Arkansas that have been classified as good on the basis of this rating will give no trouble whatever by deposition of alkali.

WATER FOR DOMESTIC USE.

PHYSICAL QUALITIES.

Entirely acceptable domestic waters are free from suspended matter, color, odor, and taste, and are fairly cool when they reach the consumer. The nearer waters approach these conditions the more satisfactory they are for general use. Suspended mineral matter clogs pipes, valves, and faucets. Growths of microscopic plants form tufts or layers in pipes and well casings and sometimes clog

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them, and detached particles give the water an unsightly appearance and stain clothes washed in it. So far as is known such growths do not cause disease, but some of them impart unpleasant odors to water. True color is usually due to dissolved vegetable matter and causes serious objection only when it exceeds 20 or 30 parts per million.

BACTERIOLOGICAL QUALITIES.

Before a water is used for domestic purposes there should be reasonable certainty that it is free from disease-bearing organisms and that it can be guarded against all chances of infection. Water from ponds, rivers, sloughs, and bayous liable to contamination by drainage from houses, privies, cesspools, stables, or irrigated fields should not be used for drinking without thorough purification. Wells should be so placed that their waters are guarded against the entrance of filth of any kind, either over the top or by infiltration. Pumps and piping in the system should also be protected. Water from a carefully cased well more than 20 or 30 feet deep is acceptable if the well is at a reasonable distance from privies, cesspools, and other sources of pollution. Many open dug wells and the pits constructed as reservoirs around the tops of many casings are frequently exposed to fecal contamination from above or through cracks in poorly built side walls. Care should be taken that the casings of deep wells do not become leaky near the surface of the ground so as to allow pollution to enter. As a matter of ordinary precaution the ground should be kept clean and water should not be allowed to become foul or stagnant near any well, no matter how deep. If shallow dug wells are necessary they should be constructed with water-tight walls extending as far as practicable into the well and also a short distance above ground. The floor or curbing should be water-tight and pumps should be used in preference to buckets for raising the water. Every possible precaution should be taken to prevent feet scrapings and similar dirt from getting into the well. Underground water is not only less likely to become contaminated if protected from surface washings, air, and light, but it keeps better and is less likely to develop microscopic plants that give it an unpleasant taste.

CHEMICAL QUALITIES.

Amounts of dissolved substances permissible in a domestic supply depend much on their nature. No more than traces of barium, copper, zinc, or lead should be present because these substances are poisonous. The occurrence of these elements in measurable amounts in ordinary waters is so rare that tests for them are not usually

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made. Any constituent present in sufficient amount to be clearly perceptible to the taste is objectionable. Water containing 2 parts per million of iron is unpalatable to many people, and even this small amount can cause trouble by discoloring washbowls and tubs and by producing rusty stains on clothes. Tea and coffee can not be made satisfactorily with water containing much iron, because a black inky compound is formed. Four or five parts of hydrogen sulphide makes a water unpleasant to the taste, and this dissolved gas is objectionable also because it corrodes well strainers and other metal fittings. The amounts of silica and aluminum ordinarily present in well waters have no special significance in relation to domestic supply. Approximately 250 parts of chlorine make a water "salty," and less than that amount may cause corrosion. Calcium and magnesium are the chief causes of the hardness of water, which is indicated by increased consumption of soap and by deposition of scale on kettles. Calcium and magnesium unite with soap, forming insuluble curdy compounds with no cleansing value and preventing the formation of a lather until these two basic radicles have been precipitated. Hardness can be measured by testing a water with a standard solution of soap, but as that test was not made in analyzing Arkansas waters the total hardness has been computed from the amounts of calcium (Ca) and magnesium (Mg) by means of the following formula:

$$\text{Total hardness as Ca } CO_3 = 2.5\ Ca + 4.1\ Mg.$$

The lower waters are in mineral content the more acceptable they are as sources of domestic supply; yet the amount of dissolved substances that can be tolerated in drinking water is much greater than that allowable in city supplies, for which problems of hardness, corrosion, pipe clogging, and general utility have to be considered, inasmuch as rather high concentrations of the common mineral ingredients have no apparent physiologic effect. Detailed inquiries by the writer in arid districts where strongly mineralized waters have to be drunk because no better supplies are available indicate that waters exceeding in strength 300 parts per million of carbonate, 1,500 parts of chloride, or 2,000 parts of sulphate are intolerable to most persons. These limits are fortunately far beyond the points where the substances in solution are clearly perceptible to taste. Though individuals are differently susceptible to the effects of such mineral matter it may be concluded that in general water without a disagreeable taste may be drunk without fear of harmful effect by its mineral ingredients. This comment does not of course take into consideration the possibility of contamination by organic matter or infection by disease germs.

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PURIFICATION OF WATER.

GENERAL REQUIREMENTS.

Purification of water is the removal or reduction in amount of substances that render waters in their raw state unsuitable for use, and it is practiced on a large scale to render the supplies safe and unobjectionable for drinking, to reduce the amount of the mineral ingredients injurious to boilers, or to remove substances injurious to machinery or to industrial products.

Removal of bacteria, especially those causing disease, and removal of turbidity, odor, taste, and iron are the principal requirements in purification of a municipal supply, elimination of bacteria and turbidity being the most important. The common methods of effecting such purification are slow filtration through sand and rapid filtration through sand after coagulation, both methods usually being combined with sedimentation.[1] Thoroughly efficient filters of either type remove 98 per cent or more of the bacteria.

Removal of scale-forming and neutralization of corrosive constituents are the chief aims in preparing water for steam making. For this two general methods are employed—precipitation by chemicals followed by sedimentation and heating with or without chemicals, usually followed by rapid filtration. The first process is carried on in cold-water softening plants and the second in feed-water heaters. Some waters that have to be used because no better supplies are available are so bad that neither of these processes is practicable, and such supplies are distilled. Distilled water, which is practically free from all dissolved and suspended matter, must also be used in certain industries. Recent improvements in multiple-effect evaporators have greatly reduced the cost of distillation, so that it is now economical to distill for industrial and domestic use many waters heretofore considered too highly mineralized to be treatable, and large factories, hotels, and even municipalities have installed multiple-effect stills.

METHODS OF PURIFICATION.

Besides the above-mentioned systems of purification many minor processes are used, sometimes alone, but more frequently as adjuncts to filters or softeners. Coarse suspended matter can be removed by rapid filtration through ground quartz or similar material in units of convenient size provided with arrangements for washing the filtering medium similar to those used in mechanical filters. Very turbid waters may be first allowed to stand in large sedimentation basins to reduce the cost of operating the filters by removing a large part

[1] For descriptions of filters see Johnson, G. A., The purification of public water supplies: U. S. Geol. Survey Water-Supply Paper 315, 1913.

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of the suspended solids. Supplies containing much iron are aerated by being sprayed into the air or by being allowed to trickle over rocks, thus precipitating the iron so that it can readily be removed by rapid filtration.

Calcium hypochlorite, sodium hypochlorite, and free chlorine gas are used to disinfect drinking water, and treatment with these substances is now widely practiced, either as an adjunct to filtration or as an emergency precaution where supplies otherwise untreated are believed to be contaminated. Disinfection by this method is not a substitute for purification by filtration for it does not remove suspended matter nor appreciable amounts of color, organic matter, swampy tastes, or odors, and it does not soften water.[1]

SLOW SAND FILTRATION.

Slow sand filtration consists in causing the water to pass downward through an artificial layer of fine sand.

On the bottom of a water-tight basin commonly constructed of concrete, perforated tiles or pipes laid in the form of a grid are covered with a foot of gravel graded in size from 25 to 3 millimeters in diameter from bottom to top. A layer of fine sand 3 to 4 feet in depth is put over the gravel, which serves only to support the sand. When water is applied on the surface it passes through the sand and the gravel and flows away through the underdrain of tiles. The suspended materials, including bacteria, are removed by the sand, the action of which is rendered more efficient by the rapid formation of a mat of finely divided sediment on the surface. When this film has become so thick that filtration is unduly retarded, the water is allowed to subside below the surface and about half an inch of sand is removed, after which filtration is resumed. The sand thus taken off is washed to free it from the collected impurities and is replaced on the beds after they have been reduced about a foot in thickness by successive scrapings. As cleaning necessitates temporary withdrawal of filters from service, they are divided into units of convenient size, usually one-half to 1 acre each, so that the operation of the entire system may not be interrupted. Most modern filters are roofed and sodded, as this practice facilitates cleaning by preventing the formation of ice, permits work on the filter beds in all kinds of weather, inhibits algæ growths, and prevents agitation of the water by wind and rain.

The foregoing paragraphs describe the esential features of a slow sand filter, but several adjuncts render this system more efficient. A clear-water basin for the filtered supply, covered to prevent dete-

[1] Johnson, G. A., op. cit., p. 71.

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rioration of the water, is provided in order that the varying rate of consumption may not affect the rate of filtration. Clarification of turbid water is rendered more economical by allowing it to stand for one to three days, during which a large portion of the suspended matter is deposited, so that the time between sand scrapings is lengthened. Objectionable odors and tastes may be removed by aeration before or after filtration. Killing the bacteria before filtration by use of chlorine or other germicides is practiced.

Slow sand filtration removes practically all the suspended matter and the bacteria. Color is only slightly reduced, and the hardness is not changed. The process is specially adapted to waters low in color, suspended matter, and animal pollution. Very small particles of clay are not removed by these filters and for water carrying such particles only for short periods occasional addition of a coagulant before filtration is advisable.

RAPID SAND FILTRATION.

The distinctive features of the rapid sand process are the coagulant and the high rate of filtration. While the raw water is entering the sedimentation basin, which is smaller than that used with slow sand filters, it is treated with a definite proportion of some coagulant, usually aluminum sulphate, which forms a gelatinous precipitate that unites and incloses the suspended material, including the bacteria, and absorbs the organic coloring matter. This combined action destroys color and makes suspended particles larger and therefore more readily removable. The proper amount of coagulant to be used is determined by the amounts of color, organic matter, and suspended matter, and by the fineness of the suspended matter, and it is best ascertained by direct experimentation with the water to be purified. Much of the trouble in operating the earlier types of rapid filters has been caused by failure to produce a good "floc" or precipitate because of improper ratios of coagulant and alkalinity. Ferrous sulphate instead of aluminum sulphate is used as a cogulant in some filtration plants; lime must be added with it in order to bring about proper coagulation.

The water, after having been mixed with the coagulant, is allowed to stand three or four hours in the sedimentation basin, where a large proportion of the suspended particles is deposited. It is then passed rapidly through beds of sand to remove the rest of the suspended matter. Many filters now in use are built in cylindrical form 10 to 20 feet in diameter, and some are so designed that filtration can be hastened by pressure. The sand, 30 to 50 inches deep and coarser than that used in slow sand filters, rests on a metallic floor containing

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perforations large enough to allow ready issue of the water but small enough to prevent passage of sand grains. When the filter has become clogged the flow of water is reversed, filtered water being forced upward through the sand to wash it and to remove the impurities, which pass over the top of the filter with the wasted water. A revolving rake with long prongs projecting downward into the sand mixes it during washing and prevents it from becoming graded into spots of coarse or fine particles. In recently constructed works rectangular filters 300 to 1,300 square feet in area have been built, and compressed air forced through the sand at intervals is used instead of a revolving rake for agitating the sand during washing. Larger orifices in the strainers are also being used, and the introduction of sand is prevented by fine gravel over the strainer pipes. The rate of filtration is from 100,000,000 to 120,000,000 gallons per acre per day. The time between washings is 6 to 12 hours, depending principally on the turbidity of the water applied to the filter.

Mechanical filtration removes practically all suspended matter, reduces the color to an amount that is unobjectionable, and under some conditions removes part of the dissolved iron. The permanent hardness of the water is increased in proportion to the amount of sulphate added by the coagulant, and if only enough lime to decompose the coagulant is added the total hardness is slightly increased. If larger amounts of lime are added, however, the total hardness is reduced. If soda ash is used in place of lime, the foaming constituents of water are slightly increased. The chemicals are always added in solution.

COLD-WATER SOFTENING.

The principal objects of water softening are to remove the substances that cause incrustations in boilers, particularly calcium and magnesium, and to neutralize those that cause corrosion. Chemicals of known strength dissolved in water are added to the raw supply in such proportion as to precipitate all the dissolved constituents that can be economically removed by such treatment. The water is then allowed to stand long enough to permit the precipitate to settle, after which the clear effluent is drawn off or the partly clarified effluent may be filtered very rapidly through thin beds of coke, sponge, excelsior, bagging, or similar material in order to remove particles that have not subsided in the tanks. The water softeners on the market differ from each other principally in the precipitant, in the filtering medium, if one is used, and in the mechanism regulating the mixing of the chemicals with the water. Installations may be of any size to suit consumption, and the process can be combined with

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rapid sand filtration for purifying municipal supplies. Among the substances that have been proposed as precipitants are sodium carbonate (soda ash), silicate, hydrate (caustic), fluoride, and phosphate, barium carbonate, oxide, and hydrate, and calcium oxide (quicklime), but of these substances lime and soda ash are almost exclusively used on account of their excellent action and comparative cheapness.

When soda ash (Na_2CO_3) and lime dissolved in water to form a solution of calcium hydrate [$Ca(OH)_2$] are added to a water in proper proportion free acids are neutralized, free carbon dioxide is removed, bicarbonates are decomposed, and iron, aluminum, and magnesium hydrates and calcium carbonate are precipitated. The precipitate in settling takes down with it a large proportion of the suspended matter. Such treatment with lime and soda ash removes the incrusting constituents practically to the limit of their solubility; the calcium added as lime also is precipitated. Sodium, potassium, sulphate, and chloride are left in solution, and the alkalies are increased in proportion to the quantity of soda ash added; that is, the foaming constituents are increased and this fixes the maximum amount of incrustants that can be treated. The maximum amount of incrustants left in a treated water is determined by the solubility of the precipitated substances and by the completeness of the reaction between the added chemicals and the dissolved matter. It has been brought below 90 parts per million in some well-treated waters. The sulphate radicle can be removed by using barium compounds, which precipitate barium sulphate, but the poisonous effect of even small amounts of barium and the relatively high cost of its salts are great objections to their use. The chlorides are not changed in amount by water softening. The chemicals should be very thoroughly mixed with the raw water and sufficient time should be allowed for complete reaction, which proceeds rather slowly, for otherwise precipitation will occur later in pipe lines or in boilers.

FEED-WATER HEATING.

Water heaters are designed primarily to utilize waste heat in stationary boiler plants by raising the temperature of the feed water and thereby lessening the work of the boilers themselves, but they also effect some purification, and many heaters have been specially designed with that end in view.

"Open" heaters, which utilize exhaust steam, are operated at atmospheric pressure. In most forms the steam enters at the bottom and the water at the top, and intimate contact between the two is obtained by spraying the water or by allowing it to trickle over or to splash against plates. In this manner the water is quickly heated

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nearly to boiling temperature. Dissolved gases are expelled, bicarbonates are decomposed, and iron, aluminum, part of the magnesium, and calcium equivalent to the carbonates after decomposition of the bicarbonates are precipitated as hydrates, oxides, and carbonates under varying conditions of temperature, pressure, and time. The precipitate agglomerates the particles of suspended matter and makes them more readily removable by sedimentation and filtration. The slowness with which the reactions take place and the presence of acid radicles other than carbonate to hold the bases in solution prevent complete removal of calcium and magnesium. The addition of soda ash in proper proportion, however, effects fairly complete precipitation of the alkaline earths, and apparatus for constant introduction of this chemical in solution may be provided. After the precipitate has been formed the water passes through filters of burlap, excelsior, straw, hay, wool, coke, or similar materials, arranged in units that can readily be cleaned. Open heaters operated without a chemical precipitant remove substances that are soft and bulky and leave in the water constituents that form hard scale; scale from water treated without chemicals in such heaters is, therefore, not so great in amount but is harder than that formed by the raw water.

"Closed" heaters are heated usually by exhaust steam but are operated at or near boiler temperature and pressure. In them the water is passed through tubes surrounded by steam or around steam pipes, and manholes or other openings are provided for cleaning the scale from the tubes. As the water is heated under pressure, some precipitation takes place, but closed heaters are not so efficient in this respect as open heaters, because they do not permit escape of the gases liberated from the water. This objection does not hold if treatment in a closed heater follows treatment in an open heater, from which the gases escape, and several systems accomplish very good purification by using a unit of each type in series.

Economizers consist essentially of water tubes set in the furnace flues in such manner as to utilize the waste heat of the flue gases. Facilities are provided for cleaning scale from the inside and soot from the outside of the tubes. The water in the tubes can be heated under pressure to much higher temperature than in open or closed heaters, and conditions of ordinary boiler operation are approximated. The precipitation of incrustants varies greatly with the normally fluctuating temperature of flue gases.

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SURFACE WATERS.

Series of analyses indicate the composition of the waters of Arkansas River at Little Rock and Mississippi River at Memphis, Tenn., but neither set correctly represents the general quality of surface waters in the lowlands of Arkansas, because both streams drain immense basins above the lowlands and receive relatively little of their discharge from them. Unfortunately, no analyses of water from the smaller rivers are available, and consequently little can be said regarding their quality. The waters of White River and practically all the smaller streams of eastern and northeastern Arkansas are undoubtedly lower in mineral content, softer, and therefore better for general use than that of either the Mississippi or the Arkansas. It is probable that none of the surface water contains as much mineral matter as that from the wells of the area and that none is too poor in quality to be adaptable to general use. As surface waters in such a low, flat country, especially in the thickly settled districts, where irrigation is extensively practiced, are likely to be subject to contamination and to carry fine silt, they should not be used for drinking without first being properly filtered.

Samples of water were collected daily from Arkansas River at the waterworks intake, Little Rock, through the courtesy of Mr. W. J. Riley, superintendent of waterworks, and tested at laboratories maintained by the United States Geological Survey from November 1, 1906, to October 24, 1907. The daily samples were united in sets of 10, and the analyses of the composites thus obtained are given in the following table. The water is highly mineralized and frequently very muddy; its average content of scale-forming ingredients is about 210 parts per million, or slightly more than 12 grains per gallon, and its average hardness is about 190 parts per million. Though it is practicable to remove the suspended matter and a large proportion of the hardening constituents by filtration and use of chemicals, the water even then is likely to foam in boilers and at times to taste brackish because of the salt in it. The striking differences from time to time in the composition of the water are caused by fluctuations in the relative discharge of the several tributaries of the river, the composition of which has been discussed by Parker[1] in connection with his studies of Kansas waters.

[1] Parker, H. N., Quality of the water supplies of Kansas: U. S. Geol. Survey Water-Supply Paper 273, 1911.

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Mineral analyses of water from Arkansas River near Little Rock, Ark.[a]

[Parts per million.]

Date, 1906–7.		Turbidity.	Suspended matter.	Coefficient of fineness.	Silica (SiO_2).	Iron (Fe).	Calcium (Ca).	Magnesium (Mg).	Sodium and potassium (Na+K).	Carbonate radicle (CO_3).	Bicarbonate radicle (HCO_3).	Sulphate radicle (SO_4).	Nitrate radicle (NO_3).	Chlorine (Cl).	Total dissolved solids.	Mean gage height (feet).
From—	To—															
Nov. 1	Nov. 10	270	172	0.64	31	0.30	84	18	351	0.0	230	136	1.8	535	1,285	3.5
Nov. 11	Nov. 20	140	96	.69	20	.30	86	22	381	.0	221	149	Tr.	568	1,339	3.6
Nov. 21	Dec. 2	140	135	.96	24	.9	39	11	123	.0	115	72	.5	186	519	5.2
Dec. 3	Dec. 19	1,000	894	.89	47	2.4	53	14	180	.0	142	95	.4	276	752	8.0
Dec. 20	Jan. 11	320	294	.92	31	1.2	25	8.9	60	.0	76	57	1.5	80	304	10.4
Jan. 14	Jan. 31	1,320	1,567	1.19	.....	.....	40	13	62	.0	106	.....	2.4	87	451	15.2
Feb. 2	Feb. 20	275	206	.75	20	.40	57	12	83	.0	155	63	3.8	107	433	8.6
Feb. 21	Mar. 7	220	228	1.04	16	.25	54	13	.....	.0	144	74	3.4	.....	460	8.1
Mar. 8	Mar. 28	450	413	.92	25	1.8	42	9.5	67	.0	131	61	1.2	82	366	9.5
Mar. 29	Apr. 12	235	233	.99	19	.8	45	11	80	.0	140	67	1.5	103	412	6.8
Apr. 13	Apr. 22	290	227	.78	20	.9	32	8.7	49	.0	106	42	1.2	65	287	7.3
Apr. 23	May 2	285	192	.67	22	1.2	42	11	74	.0	102	56	2.0	102	377	7.0
May 3	May 13	1,500	1,073	.72	54	1.8	27	6.9	33	.0	86	32	3.6	37	279	18.0
May 14	May 23	860	961	1.12	56	2.2	32	5.6	41	.0	92	43	6.3	40	305	17.4
May 24	June 2	450	460	1.02	40	1.0	31	2.7	31	.0	100	34	1.8	34	271	11.4
June 20	July 18	2,800	2,730	.97	20	.30	49	13	80	.0	181	72	2.8	87	414	10.6
July 19	Aug. 5	270	165	.61	18	.10	66	17	157	.0	196	103	1.1	213	695	5.3
Aug. 8	Aug. 17	1,000	834	.83	29	.15	96	20	415	.0	181	211	1.5	610	1,500	5.3
Aug. 18	Aug. 29	600	480	.80	13	.06	95	23	261	.0	195	212	4.4	347	1,093	4.0
Aug. 30	Sept. 8	3,000	4,119	1.37	36	.12	71	20	155	.0	189	153	1.3	181	736	5.0
Sept. 9	Oct. 6	280	162	.58	26	.33	72	17	179	[b]8.4	184	117	.3	265	806	2.8
Oct. 7	Oct. 24	900	811	.90	26	.8	72	16	155	[b]Tr.	157	98	.2	262	771	3.3
Mean.....		755	748	.88	28	.82	55	13	144	.0	148	93	2.0	203	630	.....
Percentage of anhydrous residue..		.....	.....	.....	4.6	c 2	9.0	2.1	23.5	11.9	.....	15.2	.3	33.2	.....	.....

[a] Analyses November 1, 1906, to January 31, 1907, by W. M. Barr; February 2 to 20, 1907, by Henry S. Spaulding; February 21 to September 8, 1907, by Walton Van Winkle; September 9 to October 24, 1907, by R. B. Dole, Chase Palmer, and W. D. Collins. Gage heights from records of Weather Bureau gage at Little Rock.

[b] Abnormal; computed as HCO_3 in the average.

[c] Fe_2O_3.

Above Little Rock, Arkansas River drains 158,000 square miles in Arkansas, Oklahoma, Missouri, Kansas, New Mexico, and Colorado, and its various branches are widely diverse in quality as is indicated in the accompanying table. At Arkansas City, Kans., the river carries more mineral matter than at Little Rock. Cimarron River and Salt Fork traverse great areas of gypsum-bearing rocks and salt marshes before they enter the Arkansas between Arkansas City and Little Rock, and the heavy loads of salt and silt occasionally carried by the main stream come chiefly from those tributaries. On the other hand, northeastern branches like the Verdigris and the Neosho contribute calcium carbonate waters of moderate mineral content. The diverse character of the tributaries explains why the main stream at Little Rock exhibits so great variation in composition without apparent relation to discharge; a flood on Salt Fork or the Cimarron sends down salty gypsiferous water, but a flood on a tributary like the Neosho sends down water of relatively low mineral content. This continual fluctuation in composition makes treatment of the water very difficult.

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Average chemical composition of the water of certain branches of Arkansas River above Little Rock.[a]

[Parts per million.]

Constituents.	Arkansas River at Arkansas City, Kans.	Cimarron River at Englewood, Kans.	Verdigris River at Coffeyville, Kans.	Neosho River at Oswego, Kans.
Turbidity	2,227	811	388	225
Suspended matter	1,396	666	495	194
Coefficient of fineness	1.19	1.63	1.66	.84
Silica (SiO_2)	31	35	24	20
Iron (Fe)	1.6	1.4	1.4	1.6
Calcium (Ca)	85	85	71	71
Magnesium (Mg)	24	34	11	15
Sodium and potassium (Na+K)	243	256	33	27
Carbonate radicle (CO_3)	.0	.0	.0	.0
Bicarbonate radicle (HCO_3)	253	288	261	223
Sulphate radicle (SO_4)	198	157	31	65
Nitrate radicle (NO_3)	1.8	1.7	3.2	2.9
Chlorine (Cl)	282	498	23	9.7
Total dissolved solids	990	1,334	302	304

[a] Analyses performed by F. W. Bushong and A. J. Weith in the chemical laboratory of the University of Kansas, E. H. S. Bailey, director. Each set represents the average quality from December, 1906, to December, 1907. Quoted from U. S. Geol. Survey Water-Supply Paper 273.

The following table gives the results of analyses of composite samples of water from Mississippi River at Memphis, Tenn., a few miles southeast of Marion, Ark. The water averages 150 parts per million, or slightly less than 9 grains per gallon, in its content of scale-forming matter and about 140 parts per million in hardness expressed as $CaCO_3$. It frequently carries heavy loads of silt that is contributed chiefly by Missouri River. After the mud has been removed from the water it constitutes a very fair supply for boilers, though it may be somewhat improved for that purpose by being softened. Treatment similar to that applied at the filtration plant in New Orleans would render the river water anywhere between Memphis and New Orleans thoroughly satisfactory for domestic and industrial use. Though the stream receives several tributaries between those two points, its composition is not essentially changed, for the greater portion of its discharge comes from above Memphis.

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Mineral analyses of water from Mississippi River at Memphis, Tenn.[a]

[Parts per million.]

Date, 1907–8.		Turbidity.	Suspended matter.	Coefficient of fineness.	Total iron (Fe).	Silica (SiO_2).	Iron (Fe).	Calcium (Ca).	Magnesium (Mg).	Sodium and potassium (Na+K).	Carbonate radicle (CO_3).	Bicarbonate radicle (HCO_3).	Sulphate radicle (SO_4).	Nitrate radicle (NO_3).	Chlorine (Cl).	Total dissolved solids.	Mean gage height (feet).
From—	To—																
Jan. 10	Jan. 20	420	353	0.84	.....	40	0.7	.....	14	....	0.0	146	....	0.3	6.0	198	32.8
Jan. 21	Jan. 30	350	239	.68	.....	39	.7	32	17	....	.0	129	....	.5	7.0	209	34.9
Jan. 31	Feb. 9	340	264	.78	.....	34	.20	.....	.....	....	.0	82	....	.4	7.0	168	39.5
Feb. 10	Feb. 19	270	216	.80	.....	37	.7	29	9.0	....	.0	90	....	.5	5.5	165	28.7
Feb. 20	Mar. 1	420	324	.77	.....	36	1.2	32	18	....	.0	112	....	.6	7.0	186	18.0
Mar. 2	Mar. 11	425	355	.84	.....	34	.8	43	17	....	.0	112	....	.5	10	205	25.8
Mar. 12	Mar. 21	680	615	.90	.....	43	.7	.....	12	....	.0	102	....	.3	9.5	172	29.7
Mar. 22	Mar. 31	550	505	.92	.....	40	.7	.....	10	....	.0	90	....	.9	9.5	162	34.2
Apr. 1	Apr. 10	960	740	.77	.....	34	1.3	37	12	....	.0	115	....	.2	12	188	32.9
Apr. 11	Apr. 20	680	485	.71	.....	22	1.3	27	11	....	.0	115	....	1.6	6.5	156	23.6
Apr. 21	Apr. 30	550	415	.76	.....	24	1.4	29	8.4	....	.0	104	....	1.8	8.0	161	21.5
May 1	May 10	1,150	816	.71	.....	31	2.8	24	15	....	.0	95	....	1.1	9.0	174	24.7
May 11	May 20	375	386	1.03	.....	31	1.6	26	9.7	13	.0	95	36	2.9	5.0	188	30.8
May 21	May 30	485	484	1.00	.....	19	1.1	30	7.7	13	.0	93	36	5.5	5.1	169	25.8
May 31	June 9	420	332	.79	.....	10	.12	.....	12	13	.0	122	46	5.3	6.3	188	19.2
June 11	June 20	1,600	1,421	.89	.....	19	.05	42	12	....	.0	153	63	4.9	5.9	247	27.3
June 21	June 30	1,300	1,161	.89	.....	12	1.6	36	14	....	.0	.....	53	4.9	5.5	231	28.2
July 1	July 10	1,400	1,244	.89	.....	16	.18	46	11	28	.0	156	56	5.3	8.7	245	21.9
July 11	July 20	1,000	1,185	1.18	.....	13	.30	49	15	21	.0	....	67	2.2	6.0	246	17.8
July 21	July 30	425	1,389	3.26	.....	14	.11	41	12	28	.0	172	67	2.4	12	250	22.9
July 31	Aug. 9	900	797	.89	.....	16	.08	37	9.3	24	.0	143	41	1.8	9.0	205	22.9
Aug. 10	Aug. 19	950	888	.93	.....	21	.20	39	12	21	.0	144	52	4.0	6.8	220	17.0
Aug. 20	Aug. 29	600	.....	.....	.....	22	.13	41	13	21	.0	149	47	4.6	8.0	236	14.8
Aug. 30	Sept. 8	600	451	.75	.....	17	.17	36	12	22	.0	144	40	1.7	8.5	207	14.1
Sept. 9	Sept. 18	280	307	1.10	10	22	.16	38	12	17	[b] 8.4	130	33	1.2	8.4	204	11.8
Sept. 19	Sept. 28	270	316	1.17	10	24	.14	39	12	13	[b] 7.2	146	34	Tr.	11	218	10.1
Sept. 29	Oct. 8	220	203	.92	7.4	23	.22	39	10	20	[b] 7.2	145	37	Tr.	9.8	219	10.0
Oct. 9	Oct. 18	240	221	.92	8.8	14	.5	35	10	16	[b] Tr.	142	34	Tr.	9.4	198	10.9
Oct. 19	Oct. 28	270	198	.73	11	21	.37	36	13	17	[b] 7.2	134	34	.20	9.6	208	9.9
Oct. 29	Nov. 9	240	316	1.32	8.8	20	.12	43	13	18	[b] 3.6	159	40	Tr.	11	235	7.0
Nov. 10	Nov. 19	230	203	.88	7.9	21	.52	42	13	28	[b] 7.2	159	39	Tr.	14	257	9.0
Nov. 20	Dec. 1	230	215	.93	13	10	.42	36	11	18	[b] Tr.	127	43	Tr.	16	200	12.0
Dec. 2	Dec. 12	180	187	1.04	8.0	5.6	.07	33	10	14	[b] 8.4	106	29	Tr.	9.0	162	11.6
Dec. 13	Dec. 22	170	160	.94	3.5	24	.24	36	12	17	[b] 13	115	32	1.7	9.6	201	8.4
Dec. 23	Jan. 1	265	265	1.00	7.9	26	.56	33	10	16	[b] Tr.	124	35	1.5	9.6	195	13.5
Mean.....		556	519	.97	.....	24	.61	36	12	19	.0	129	43	1.7	8.6	202	.....
Percentage of anhydrous residue.....		.....	.....	.....	.....	11.5	[c] 4	17.3	5.7	9.1	30.5	....	20.6	.8	4.1	....	.....

[a] Analyses January 10 to May 10, 1907, by Jas. R. Evans; May 11 to September 8, 1907, by Walton Van Winkle; September 9, 1907, to January 1, 1908, by R. B. Dole, Chase Palmer, and W. D. Collins. Samples collected in main current by T. D. Shroyer. Gage heights from records of gages at Memphis maintained by Weather Bureau and Corps of Engineers, U. S. Army.

[b] Abnormal; computed as HCO_3 in the average.

[c] Fe_2O_3.

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GROUND WATERS.

CHEMICAL ANALYSES.

Forty-seven mineral analyses of water were made especially for this report by Dr. J. R. Bailey, of the University of Texas, in general accordance with the methods outlined[1] in Water-Supply Paper 236, except that somewhat smaller portions of the sample were taken for certain determinations; also the content of the alkalies (Na+K) was calculated from the reacting values of the acid and the other basic radicles in all analyses except those in which silica was determined. Where silica was determined the alkalies were weighed as the mixed chlorides (NaCl+KCl). Besides those by Dr. Bailey, 21 analyses were procured from various sources. Most of these analyses were originally expressed in grains per United States gallon in hypothetical combinations, but they have been recomputed to ionic form in parts per million in order that they may be compared with other data. Expression of the results of water analyses in parts per million has been generally adopted by sanitary and research chemists and by many technical chemists in place of expression in grains per gallon, and the exclusive use of the former unit is delayed only by disinclination to adjust mental standards to the decimal system.

For convenience of those who may desire to transfer the results to other forms of expression it may be stated that multiplying the number of parts per million by 0.058 gives the equivalent in grains per United States gallon of 231 cubic inches; multiplying it by 0.07 gives the equivalent in grains per imperial gallon; and multiplying it by 0.00833 gives the equivalent in pounds per thousand gallons.

The analytical methods commonly employed in examining water permit the estimation of the elements and radicles present, the determination of the total amount of mineral matter in solution, and the more or less approximate separation of the incrusting from the nonincrusting constituents. Further than this, however, ordinary chemical tests give little knowledge regarding the chemical composition of mineral waters and consequently the exact amounts of the different salts in solution are largely conjectural. Though such salts as sodium chloride, potassium carbonate, and magnesium sulphate, for example, are probably present they are not determined as such and their exact amounts can not be computed from the analytical data. Because of that the ionic form of stating the analyses—that is, stating the radicles present—has been used in this report. The figures thus give facts and not opinions and present actual laboratory

[1] Dole, R. B., The quality of surface waters in the United States: U. S. Geol. Survey Water-Supply Paper 236, pp. 9–39, 1909.

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0	67
...	83
3	89
7	78
6	32
0	98
0	97
22	49
8	24
9	32
6	64
	106
4	Trace.
5	12
8	22
9	25
0	64
9	64
...	.....
7	89
1	54
...	.....
9	69
7	78
27	94
9	87
...	.....
1	66
9	64
7	50
4	70
8	55
1	115
6	103
2	119
26	91
7	76
...	43
9	7.2
2	92
9	85
6	78

r 195, pp. 185–86, 19

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results for consideration and criticism by others than those who made the tests.

The available chemical analyses of water from wells in eastern and northeastern Arkansas are given in the accompanying table, which is arranged alphabetically by counties. The position of the wells from which samples were taken is indicated in Plate XI. The table gives the water-bearing stratum from which the supply of each well chiefly comes, as determined by Messrs. Stephenson and Crider. The total hardness, the probable content of scale-forming and of foaming ingredients, and the probability of corrosion of each water have been computed from the data of the analyses and entered in the table. Each water has also been classified in respect to its availability for boiler and domestic use and for irrigation. These computations and ratings have been made in accordance with the formulas and standards already discussed (pp. 281–291). It should be thoroughly recognized that the ratings refer only to the effect of the mineral ingredients of the waters and not to other conditions. The statement that a water is good for irrigation implies that it does not contain enough alkali to cause trouble under the conditions of irrigation commonly practiced in this country, but the statement does not take into account soil or crop conditions. The statement that a water is good for domestic use implies likewise that it does not contain harmful or otherwise objectionable mineral substances in solution, but the water may or may not be exposed to harmful pollution.

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FIELD ASSAYS.

The field assays by Messrs. Stephenson and Crider in the following table were made according to the methods described by Leighton.[1] The results are necessarily less accurate than those obtained by analysis in a laboratory, because of the approximate nature of the tests and because of the conditions under which the examinations were made. Iron, carbonate, bicarbonate, sulphate, and chlorine were estimated, but as total hardness was not estimated it is impracticable to interpret except in a general way the results of the tests. The figures serve, however, to amplify the data in the table of analyses (p. 302), as they furnish some information regarding the water of wells not otherwise examined. The total mineral content of the waters has been calculated from the estimates of the acid radicles. The relatively high color reported for many of the samples is rather surprising as most deep ground waters are only slightly colored. If these figures represent true color and not the apparent color caused by a slight precipitate of iron or other substance they indicate the presence of more or less vegetable matter, not necessarily harmful, however, in the alluvial deposits.

[1] Leighton, M. O., Field assay of water: U. S. Geol. Survey Water-Supply Paper 151, 1905. See also Dole, R. B., The rapid examination of water in geologic surveys of water resources: Econ. Geology, vol. 6, pp. 340–362, 1911.

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No.	Location.		Carbonate radicle (CO_3).	Bicarbonate radicle (HCO_3).	Sulphate radicle (SO_4).	Chlorine (Cl).	Total dissolved solids.[a]
	ARKANSAS COUNTY.						
1[b]	Dewitt	Driven	0	433	0	35	460
2[b]	.....do	Driven	0	273	0	15	290
3[b]	.....do	Bored	0	371	Trace.	95	500
	CRAIGHEAD COUNTY.						
4[b]	Brookland	Bored	0	572	0	85	660
5[b]	.....do	Town	0	84	0	10	120
6[b]	Culberhouse	Well o	0	334	65	100	570
7[d]	Dee	Well o	0	334	100	10	490
8[b]	Greenboro	Well o	0	48	0	15	100
9[b]	Gubertown, 2 miles northwest of.	Still H	0	36	0	15	90
10[b]	Jonesboro	Well a	6	1,145	0	270	1,500
11[b]	.....do	Well a	0	143	0	25	180
12[b]	Nettleton	Driven	0	215	Trace.	30	260
13[b]	.....do	Driven	0	429	60	105	660
14[b]	.....do	Well o	0	95	0	10	130
15[b]	O'Bear	Driven	0	382	0	25	400
16[b]	.....do	Driven	0	359	0	25	380
	CRITTENDEN COUNTY.						
17[d]	Ivoton	Driven	0	311	Trace.	25	340
18[d]	Marion	Driven	0	383	0	10	380
19[d]	.....do	Dug w	0	227	100	95	540
20[d]	.....do	Lake M	12	96	0	10	150
21[b]	Turrell	Well o	0	526	0	25	520
	GREEN COUNTY.						
22[b]	Lorado	Town d	0	335	0	15	340
	LONOKE COUNTY.						
23[d]	Baucum	Driven	0	430	0	15	420
24[d]	Blakemore	Dug w	0	239	35(?)	65	390
25[d]	England	Town	0	359	45	25	450
26[d]	Jebb	Driven	0	239	0	15	260
27[d]	Jebb, 3 miles west of	Driven	0	239	140	15	460
28[d]	"Old River"	Dug w	0	419	40	30	500
29[d]	Toltec	Well of	0	227	60	10	330
30[d]	Tomberlins	Dug w	0	107	0	20	150
	MISSISSIPPI COUNTY.						
31[d]	Blytheville	Dug w	0	96	0	40	180
32[d]	.....do	Driven	0	442	.....	25	450
33[d]	.....do	Driven	0	196	110	35	420
34[d]	Manila	Driven	0	48	Trace.	15	95
35[d]	.....do	Driven	0	36	Trace.	40	130
36[d]	Osceola	Driven	0	627	0	15	590
37[d]	.....do	Well at	0	143	0	20	180
38[d]	.....do	Cistern	31	63	0	10	150
	PHILLIPS COUNTY.						
39[b]	Trenton	Driven	0	382	40	10	430
	POINSETT COUNTY.						
40[b]	Tyronza	Well ne	0	119	Trace.	25	170
41[b]	Weiner	Driven	0	310	0	15	320
42[b]	.....do	Well of	0	359	0	15	360
	PRAIRIE COUNTY.						
43[d]	Biscoe	Driven	0	48	0	50	150
44[d]	Devall Bluff	Well of	0	454	Trace.	20	450
45[d]	.....do	Driven	0	454	(k)	25	470
46[d]	Devall Bluff, ½ mile south of.	Bored w	0	84	380	300	1,200
47[d]	Devall Bluff	Well of	0	382	(k)	25	400
48[d]	Hazen	Town w	0	359	0	15	360
49[d]	.....do	Bored w	0	431	50	120	670
50[d]	Tollville	Well of	0	454	Trace.	20	450
51[d]	Tollville, ¾ mile west of	Well of	0	358	Trace.	105	510
	PULASKI COUNTY.						
52[d]	Scott	Well of	0	670	85	25	770

[a] Computed by t
[b] Assay by L. W aring stratum 840–864 feet.
[c] Turbidity, 80 p d with ground water.
[d] Assay by A. F.
[e] Depth of princi
[f] Depth of princ

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QUALITY IN RELATION TO WATER-BEARING STRATUM.

QUATERNARY ALLUVIUM.

More than five-sixths of the wells whose waters have been analyzed draw chiefly from the alluvium, and most of these are situated west of Crowleys Ridge (see Pl. XI) in the Advance lowlands. Indeed, the economic value of ground waters in this area is practically a question of the value of waters from the alluvium, which almost everywhere yields large supplies at moderate depths. According to Mr. Stephenson, the alluvium consists of loams, clays, sands, and gravels; in the Pleistocene deposits there is a general downward gradation from fine surface silts or loams through compact clays and fine sands to coarse sands and gravels at the base. Dark carbonaceous clays, logs, limbs of trees, and peaty accumulations representing buried swamp deposits are occasionally encountered in boring wells.

The following table gives a résumé of the analyses of water from the alluvium and shows the approximate average composition of the supplies and the general range of their constituents. The figures have been rounded off to avoid appearance of undue accuracy. There is a wide range in mineralization, as may be expected in water from any irregularly bedded deposit, and a few waters exceed the limits noted in the table. More than three-fourths of the supplies, however, range in mineral content from 200 to 520 parts and in hardness from 150 to 400 parts per million. In other words, they are calcium carbonate waters of moderate mineral content, rather hard, but containing relatively little alkali. Sulphate (SO_4) exceeds 40 parts per million in only five analyses of water from the alluvium and is generally less than 20 parts. Chlorine exceeds 40 parts in nine, but is as low as 10 parts in a large proportion.

Approximate chemical composition of waters from the alluvium in eastern and northeastern Arkansas.

Constituents.	Approximate average.		Approximate range (parts per million).	
	Parts per million.	Percentage of anhydrous residue.	Highest.	Lowest.
Silica (SiO_2)	40	11	.....	.....
Calcium (Ca)	75	20	120	25
Magnesium (Mg)	25	7	40	10
Sodium and potassium (Na+K)	25	7	70	5
Carbonate radicle (CO_3)	0	44	0	0
Bicarbonate radicle (HCO_3)	340	.....	550	120
Sulphate radicle (SO_4)	15	4	80	1
Chlorine (Cl)	25	7	85	5
Total dissolved solids	370	.....	800	160
Total hardness as $CaCO_3$	280	.....	500	120

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The hardness of the waters indicates the presence of a rather large proportion of calcareous material in the alluvium, and that condition indeed might be expected in view of the great abundance of limestone in the upper basin of Mississippi River and its great tributaries, from which the alluvium is largely derived. Compact crystalline limestones and dolomites comprise much of the older sedimentary formations there, and later deposits are also strongly calcareous. Contrary to common belief the débris carried from limestone regions is not completely robbed of its calcareous material by the water that removes it and later deposits it as alluvial material; limestone even when finely divided is dissolved in appreciable quantity only in so far as the carbon dioxide in the contiguous water renders it soluble; consequently alluvium derived from limestone retains much of its calareous material and wherever waters containing free carbon dioxide percolate through such alluvium they may become as hard as those traversing limestone itself.

It is interesting to note the similarity in composition of water from the alluvium of Arkansas and that from calcareous deposits in Indiana and Ohio. (See table, p. 307.) The unconsolidated deposits of the latter States are mostly glacial drift and yield waters of similar quality; the limestones of the same region also yield similar supplies. The alluvium of Arkansas yields water containing practically as much bicarbonate, only slightly less calcium and magnesium, but much less sulphate. The alluvial water contains about three-fourths as much mineral matter, which in comparison with the waters of Indiana and Ohio is lower in its percentage of sulphate and slightly higher in its percentage of carbonate. The ratios of magnesium to calcium in lines A to E, inclusive, are, respectively, 1:2.6, 1:2.9, 1:2.0, 1:2.6, and 1:3.0—that is, with the exception of water from the "Niagara" limestone, which is highly dolomitic, these waters contain 33 to 39 per cent as much magnesium as calcium. These comparisons show that this alluvium yields water almost as hard as that from old compact limestones, and they also show that even thoroughly washed material may strongly impregnate with mineral matter the waters percolating through it.

The water from the limestone of the Vicksburg formation of Georgia, whose average composition is indicated in lines F and L of the following table, is more or less typical of supplies from the calcareous Tertiary sediments of Georgia and it is inserted for comparison. The water is very much softer and lower in mineral content than that of the alluvium in Arkansas, and the relative proportions of calcium and magnesium are entirely different.

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Comparison of the quality of water from the Quaternary alluvium of eastern Arkansas with that of ground waters in Indiana, Ohio, and Georgia.

Mineral content in parts per million.

	Number of analyses averaged.	Silica (SiO_2).	Iron (Fe).	Calcium (Ca).	Magnesium (Mg).	Sodium and potassium (Na+K).	Carbonate radicle (CO_3).	Bicarbonate radicle (HCO_3).	Sulphate radicle (SO_4).	Chlorine (Cl).	Dissolved solids.
A	120	20	0.8	90	35	30	0	390	90	50	500
B	169	18	.8	91	31	18	0	306	76	47	467
C	20	20	.5	80	40	20	0	360	80	25	440
D	80	18	1.8	82	31	27	0	341	70	19	466
E	54	40	.....	75	25	25	0	340	15	25	370
F	28	20	1	40	5	10	0	140	20	5	190

Percentage composition of the anhydrous residues.

G	.....	4	0	18	7	5	38	.....	18	10	.....
H	.....	4	0	21	7	4	35	.....	18	11	.....
I	.....	4	0	18	9	5	40	.....	18	6	.....
J	.....	4	0	20	7	7	40	.....	17	5	.....
K	.....	11	0	20	7	7	44	.....	4	7	.....
L	.....	12	1	24	3	5	40	.....	12	3	.....

A, G. Unconsolidated deposits of southwestern Ohio.
B, H. Unconsolidated deposits of north-central Indiana.
C, I. "Niagara" limestone of southwestern Ohio.
D, J. Limestones yielding fresh water in north-central Indiana.
E, K. Quaternary alluvium of eastern Arkansas.
F, L. Limestone of Vicksburg formation of Georgia.
(A, G, C, and I from U. S. Geol. Survey Water-Supply Paper 259, p. 212, 1912; B, H, D, and J from U. S. Geol. Survey Water-Supply Paper 254, pp. 260-261, 1910; and F and L from U. S. Geol. Survey Water-Supply Paper 341, pp. 522-523, 1915.)

The iron content of waters from the alluvium of Arkansas differs greatly from place to place, and some of the supplies carry enough to render them distasteful and capable of staining fabrics washed in them. Mr. Stephenson mentions the appearance in the surface materials of iron in the form of small limonite concretions, whose irregular distribution probably explains the difference in iron content of the waters.

The waters of the alluvium are generally potable, but they are so hard that most of them have been rated as only fair for domestic use. Fortunately, the greater proportion of the hardness, being temporary, can be removed by boiling the waters and allowing the sediment thus produced to settle. The waters are, almost without exception, good for irrigation and can be used without fear of their causing accumulations of alkali in the soil. Few would be likely to foam in or corrode boilers, but all carry considerable soft scale forming matter and for boiler use could be greatly improved in preheaters or cold water softening plants. The classification of them as fair to poor for boiler use is rather more severe than the classification adopted by some railroads traversing Arkansas, but it corresponds to the ratings outlined on pages 284–287.

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CRETACEOUS AND TERTIARY FORMATIONS.

The analyses of water from Tertiary and Cretaceous formations in eastern Arkansas are so few that little can be deduced regarding their general quality. Analyses 15, 22, and 48 in the table opposite page 302 represent calcium carbonate waters of moderate mineral content from the Wilcox formation, which comprises strata of sands, clays, quartzites, and lignites. No. 45 in the same table is a partial analysis of water from the Claiborne formation in Phillips County. A well 1,495.5 feet deep in Mississippi County is believed to draw its supply chiefly from Cretaceous sands (see analysis No. 39), and a shallower well in White County (analysis No. 64) enters Carboniferous strata. Three other wells in St. Francis, Lee, and Monroe counties (see analyses Nos. 58, 28, and 42) enter undifferentiated formations of the Eocene series. The latter of these yields a salt water of high mineral content.

QUALITY IN RELATION TO GEOGRAPHIC POSITION.

Waters containing moderately large amounts of sulphate or chloride have been occasionally encountered in eastern and northeastern Arkansas but with little apparent regularity, and they probably are derived from local gypsiferous or saline beds that may owe their origin to influxes of highly mineralized silts from the area now included in Oklahoma and southwestern Kansas. Though the waters from the alluvium of the lowlands range in mineral content approximately from 160 to 800 parts per million, the available analyses do not indicate any definite geographic distribution of waters of high or low mineral content. Most of the ground waters are potable, acceptable for irrigation, and capable of being purified for industrial use. Consequently the occasional occurrence of waters relatively high in mineral content is not especially serious.

Of the 68 waters whose analyses are given in the table (p. 302) only 10 exceed 50 parts per million in content of sulphate or 100 in content of chlorine. Six of these are from wells in the area between Arkansas and White rivers. The data of the field assays (p. 304) indicate that waters rather high in sulphate and chlorine come from some but not by any means all wells in the same area. The owners of a few wells in Arkansas and Prairie counties have reported saline waters (pp. 150, 251). All these facts together lead to the conclusion that local deposits of gypsiferous and saline material may be more numerous in the alluvium between Arkansas and White rivers than elsewhere in northeastern Arkansas. The water of Arkansas River contains a large proportion of sulphate and chlorine, and past meandering of this stream may explain the presence of the mineralized alluvial spots. Mr. Stephenson states (p. 271) that the ground waters

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have a distinct brackish taste in a considerable area in the eastern part of White County, particularly in the vicinity of West Point and Worden and east of Russell. Greater development of ground waters in the lowlands will doubtless result in the discovery of similar areas.

QUALITY IN RELATION TO DEPTH OF WELL.

The averages in the following table indicate that wells less than 100 feet deep in the alluvium are likely to yield waters of somewhat lower mineral content than deeper ones, but this apparent difference may be a fortuitous coincidence of figures, though the number of analyses that have been averaged is fairly great. Aside from this difference the comparative quality of waters from various depths in the alluvium, as indicated by the results in the table opposite page 302, appears to depend entirely on the locality. This condition may be expected because the alluvium is irregularly bedded.

Mineral content of water from the alluvium of eastern and northeastern Arkansas in relation to depth of well.

Depth of wells.	Number of analyses averaged.	Average total dissolved solids.	Average total hardness as $CaCO_3$.
Feet.		*Parts per million.*	*Parts per million.*
60–100	12	366	254
101–149	22	375	296
150–200	16	378	295

ECONOMIC VALUE.

The probable value of the waters that have been analyzed is indicated in the last three columns of the table opposite page 304. So few analyses of supplies from Cretaceous and Tertiary strata are available that no general statements regarding their usefulness can be made.

The waters of the alluvium in general are calcium carbonate waters of moderate mineral content. They are rather hard, but as most of the hardness is carbonate or temporary, they can be softened by being boiled. Some carry enough iron to taste unpleasant, but most are potable. Practically all are suitable for irrigation. Few are likely to cause foaming or corrosion in boilers, but all carry considerable scale-forming matter and for boiler use could be greatly improved in preheaters of cold water softening plants. For these reasons they have been rated as fair or poor for boiler use in their natural state, but capable of being made satisfactory at relatively little expense.

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INDEX.

A.

Page.

Acknowledgments for aid..... 14-15
Advance lowland, prairie phase of, plate showing..... 26
topography of..... 25-28
Alicia, log of well at..... 204
Alluvium, Pleistocene, correlation of..... 120-121
Pleistocene, general features of..... 114-116
Quaternary, analyses of waters from.. 305-307
economic value of waters from..... 309
Recent, deposition of..... 132
Almyra, log of well near..... 153
American Railway Engineering and Maintenance of Way Association, ratings of waters by..... 286-287
Analyses of ground waters..... 302-303
table showing..... 302
Area covered by this report..... 22
Argenta, logs of wells at..... 258-259
water supply of..... 258
Arkansas County, geology of..... 150
physiography of..... 149-150
water resources of..... 150-153
wells in, data on..... 154-159
Arkansas River, depth of scour of..... 121
sources of minerals in..... 299
water of, analyses of..... 299, 300
quality of..... 298
Artesian waters. *See* Waters, artesian.
Ashley, G. H., on the deposits penetrated on Hen and Chicken Island..... 177
Ashport Bend, logs of borings at..... 226-227
Assays of ground waters..... 304
Augusta, log of well at..... 276
section of alluvium at..... 117
water supply of..... 276
Austin, section of Eocene beds at..... 84

B.

Bacteriological qualities of water for domestic use..... 290
Bailey, J. R., chemical analyses by..... 302
Bald Knob, log of well at..... 272
Barton, wells at..... 138, 239
Bartsch, Paul, acknowledgment to..... 15
fossils determined by..... 106-107, 108
Bayou De Vue, course of..... 26
Beebe, marl of the Midway formation at.... 49-50
Beech Grove, log of well near..... 189
Benton Ridge, Mo., situation of..... 23
Berry, E. W., acknowledgment to..... 15
fossils determined by..... 58, 59, 62, 63
on the assumed unconformity at the base of the Claiborne..... 66
on the correlation of a bed on Bolivar Creek..... 63

Page.

Bibliography..... 15-22
Big Creek, course of..... 26
Big Lake Highlands, deposits composing.... 114
situation of..... 29
Big Prairie. *See* Sikeston Ridge.
"Big Spring," section of the Lafayette formation near, and 2½ miles north of Helena..... 94-95
section of the Lafayette formation south of, and 2½ miles north of Helena. 95
sections of loess near..... 94, 95
Black River, course of..... 26
Black Rock, log of well near..... 204
Blytheville, log of well near..... 225-226
well at..... 137
Boiler compounds, efficiency of..... 283-284
Boiler scale, formation of..... 281-282
Boiler troubles, remedies for..... 283
Boilers, rating of waters for use in..... 284-287
Bolivar Creek, section of the Wilcox formation on..... 61-62
Bono, log of well near..... 171
section of the Lafayette formation at..... 91
section of the Wilcox formation northeast of..... 61
Bonsteel, J. A., on the Crowley silt loam..... 147
Booty, log of well near..... 153
Boydsville, exposure of sandstone near..... 58
Bradford, occurrence of the Midway formation at..... 50-51
Brinkley, logs of wells at and near..... 230-231
well at..... 138
Buckshot lands, nature of..... 26
Burdette, log of well at..... 226

C.

Cabot, logs of wells at and near..... 217
occurrence of the Midway formation at .. 49
Cache River, course of..... 26
Cairo, Ill., fossil shell found at..... 43-44
Call, R. E., on a section of the Jackson formation at Red Bluff..... 81-82
on a section of the Jackson formation northeast of Forrest City..... 76
on a section of the Wilcox formation on Bolivar Creek..... 61-62
on exposures of the Claiborne formation on Spencer Creek..... 68
on exposures of the Wilcox formation near Gainesville..... 59
on sections of the loess west of Jonesboro. 110
on silicified logs in clay north of Gainesville..... 58-59
on the clays exposed in Chalk Bluff..... 57-58
section of the Midway formation recorded by..... 50

Digitized by Google

Page.

Cross County, water resources of..... 180–183
wells in, data on..... 184–185
Crowleys Ridge, topography of..... 22–23

D.

Dall, William H., fossils determined by..... 108
Depth, quality of waters in relation to..... 309
Des Arc, logs of wells at..... 252
Devall Bluff, log of well near..... 253
Domestic use, requirements of water for.... 289–291

E.

Earl, water supply of..... 175
well at..... 137
Eocene deposition, erosion following..... 126
Eocene series, formations of..... 44–65
formations of, ground water in..... 136–135
undifferentiated beds of..... 84–88
Eocene time, depression and deposition in. 124–126

F.

Fairoaks, logs of wells at and near..... 183
Feed water, heating of..... 296–297
Field assays of ground waters, table showing. 304
Filtration, rapid sand, process of..... 294–295
slow-sand, process of..... 293–294
Foaming of boilers, cause of..... 282–283
Forrest City, section of loess east of..... 107
section of loess northeast of..... 108
section of the Jackson formation northeast of..... 76
water supply of..... 265
wells at..... 137
Fossils, occurrence of, in the Claiborne formation..... 69
occurrence of, in the Jackson formation. 78, 80, 83
in the loess..... 106–107, 108, 128
in the Midway formation. 48, 49, 50, 51, 52, 53
in the Wilcox formation..... 58, 59, 62, 63
in Upper Cretaceous deposits..... 38, 40, 41, 42, 43
Fourche Creek, fossils from..... 49
section of the Midway formation on..... 48
Fuller, M. L., on the conditions governing artesian flows..... 140–141
supervision by..... 14
Fuller, W. H., acknowledgments to..... 15, 144

G.

Gainesville, exposures of loess at..... 111
sections of Lafayette formation near..... 90
Geographic position, quality of waters in relation to..... 308–309
Geologic cross sections, plates showing..... 32, 34
Geologic history, events of..... 123–132
Georgia, calcareous deposits in, content of waters from..... 306–307
Gilkeson, logs of wells near..... 171
Glenn, L. C., on the relation of Pleistocene deposits to the Lafayette formation..... 87–88
Grandglaise, exposure of loam south of..... 111
exposures of the Midway formation near. 52–53
Grandglaise terrace, topography of..... 23–24

Digitized by Google

Page.

Grand Prairie, deposits composing..... 114
situation of..... 29
Greene County, geology of..... 187–188
physiography of..... 186–187
water resources of..... 188–189
wells in, data on..... 190–191
Greensboro, log of well at..... 170
Ground-water resources of eastern and northeastern Arkansas, map showing.. 134
Ground waters, field assays of, table showing. 304
Gulf Coastal Plain, area of, in Arkansas..... 13
deposits underlying..... 14
geologic map of..... 30
topography of..... 14

H.

Hardpan, nature of..... 115
Harris, G. D., fossils determined by..... 80, 83
on Cretaceous deposits in eastern Arkansas..... 40, 41
on exposures of the Jackson formation on Arkansas River..... 79–81
on fossils from limestone ledges near Bradford..... 51, 53
on fossils from localities north of Bradford 53
on fossils in the Midway formation..... 49
on the use of the term Midway..... 46
Harrisburg, exposures of the Lafayette formation at..... 91–92
logs of wells at and near..... 244–245
Hazen, log of well near..... 253
water supply of..... 252
Helena, section of loess in..... 106
sections of the Lafayette formation near.. 94–95
water supply of..... 236
logs of borings at and near..... 237–239
wells at..... 138
Hen and Chicken Island, log of prospecting well on..... 177
Higginson, log of well at..... 272
Hilgard, E. W., fossils determined by..... 78
on the correlation of beds penetrated at Helena..... 78–79
Holland, log of well at..... 216
Hunter, logs of wells near..... 277
Hydrick, log of well near..... 183

I.

Igneous rocks of Cretaceous age, occurrence of. 34–35
Independence County, geology of..... 192–193
physiography of..... 192
water resources of..... 193–194
Indiana, calcareous deposits in, content of waters from..... 306–307
Irrigation, rating of waters for..... 287–289

J.

Jackson County, geology of..... 195–196
physiography of..... 194–195
water resources of..... 196–197
Jackson formation, correlation of..... 82–84
deposition of..... 125–126
general features of..... 73–75
literature of..... 73–74
sands and clays of, plate showing..... 76
Jacksonville, log of well at..... 259

Page.

Jefferson County, geology of..... 198
physiography of..... 197–198
water resources of..... 198–199
wells in, data on..... 200–201
Jones Ridge, loess in..... 111
topography of..... 24
Jonesboro, logs of wells at and near..... 169
section of the Lafayette formation southwest of..... 91
sections west of..... 110
Jurassic deposits, absence of..... 123

K.

Knapp, S. A., on soils suitable for rice culture. 148
Knobel, logs of wells at and near..... 162, 163

L.

Lafayette formation, correlation of..... 97–100
deposition of..... 126–127
erosion following..... 127
general features of..... 85–89
gravel of, plates showing..... 88
ground waters in..... 138
plate showing..... 76
unconformable contact of, with loess, plate showing..... 102
Lagrange, logs of wells near..... 211
Lake City, well at..... 170
Lakes, general features of..... 133
L'Anguille River, course of..... 26
Lawrence County, geology of..... 202–203
physiography of..... 202
water resources of..... 203–205
wells in, data on..... 206–207
Lee County, geology of..... 209
physiography of..... 208
water resources of..... 209–211
wells in, data on..... 212–213
Limestone, débris from, calcareous material in. 306
pebbly, with interbedded layers of the Midway formation, plate showing. 52
Little Crow Creek, section of the Jackson formation on..... 76–78
sections of the Lafayette formation on 76–78, 93
Little River, course of..... 28
Little Rock, exposures of bog iron ore in..... 41
water supply of..... 257–258
Loess, correlation of..... 112–113
deposition of..... 127–129
exposure of, on Crowleys Ridge, plate showing..... 102, 108
on Little Crow Creek, plate showing. 76
general features of..... 100–105
"old soil" zone in, plate showing..... 108
unconformable contact of, with the Lafayette formation, plate showing. 102
Lonoke, logs of wells at and near..... 216, 219
Lonoke County, geology of..... 214–215
physiography of..... 214
water resources of..... 215–219
wells in, data on..... 220–223
Lovelady Place, Greene County, section of the Wilcox formation on..... 60
Luxora, water supply of..... 226
Lynn, log of well near..... 205

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M.

Page.

Marbut, C. F., on the later geologic history of the Mississippi embayment.... 129–131
Marianna, log of well at..... 210
water supply of..... 138, 210
Marked Tree, depth of wells at..... 137
log of well at..... 245
Marmaduke, logs of wells near..... 189
Marvell, exposures of alluvium at..... 118
Memphis, Tenn., log of municipal well at... 176–177
Mesozoic formations, generalized section of.. 34
Midway formation, deposition of..... 125
exposures of..... 48–53
general features of..... 45–48
Minerals, dissolved, accumulation of in the soil..... 287
Mississippi County, geology of..... 224
physiography of..... 224
water resources of..... 225–227
wells in, data on..... 228
Mississippi embayment, deposits in..... 31–32
extent of..... 13
structure of..... 31
Mississippi lowland, topography of..... 28–29
Mississippi River, depth of scour of..... 122
diversions of..... 131
water of, analyses of..... 300–301
Missouri, occurrence of the Wilcox formation in..... 57
Monroe County, geology of..... 229–230
physiography of..... 229
water resources of..... 230–231
wells in, data on..... 232–233
Moro, log of well near..... 211
Mound, low circular, at Bald Knob, plate showing..... 26
Mounds, small, origin of..... 30–31

N.

Nacatoch (?) sand, exposures of, in Independence County..... 37–40
exposures of, south of Independence County..... 40–41
general features of..... 36–37
Neosho River, water of, analysis of..... 300
Nettleton, log of well at..... 170
Newark, Cretaceous fossils from..... 41–42
exposures of loess near..... 111
log of well at..... 194
section of the Lafayette formation west of. 97
Newport, log of well at..... 197
water supply of..... 196
well of ice company at..... 196
Norton, E. G., acknowledgments to..... 15, 144

O.

Obear, log of well near..... 171
Ohio, calcareous deposits in, content of waters from..... 306–307
O'Kean, wells at..... 262
Old Grandglaise, section of alluvium at site of. 116
"Old soil" in loess, occurrence of.....102, 109, 112
plate showing..... 108
Osceola, water supply of..... 225
Ouachita Mountains, situation of..... 13

Page.

Ozark province, area of, in Arkansas..... 13
rocks underlying..... 13–14
topography of..... 13, 22

P.

Paleozoic rocks, deposition of..... 123
deposition of, erosion following..... 123
depth to..... 33
exposures of..... 32–33
Paragould, exposures of loess west of..... 110
section of Lafayette formation west of.... 90
water supply of..... 188–189
Parkin, depth of wells at..... 137
log of well at..... 182
Phillips County, geology of..... 235
physiography of..... 234–235
water resources of..... 236–239
wells in, data of..... 240–241
Phillips post office, section of the Lafayette formation west of the site of..... 94
Physical qualities of water for domestic use. 289–290
Piggott, logs of wells at..... 162
Pleistocene series, deposits of..... 100–121
Pliocene series, formations of..... 86–100
Poinsett County, geology of..... 243
physiography of..... 242
water resources of..... 243–247
wells in, data of..... 248–249
Ponds, general features of..... 133
Poplar Creek, section of Lafayette formation on..... 90
section of Wilcox formation on..... 60
Powhattan, exposures of loess at..... 111
Prairie County, geology of..... 250–251
physiography of..... 250
water resources of..... 251–253
wells in, data of..... 254–255
Pulaski County, geology of..... 256–257
physiography of..... 256
water resources of..... 257–259
wells in, data of..... 260
Purification of water, general requirements of. 292
methods for..... 292–298

Q.

Quartz pebbles in the Lafayette formation, origin of..... 99
Quartzite, exposures of, in Craighead, Greene, and Clay counties..... 61
Quaternary formations, distribution and character of..... 100–123
ground waters in..... 138–139

R.

Randolph County, geology of..... 261–262
physiography of..... 261
water resources of..... 262
Rating of waters for boilers..... 284–287
for irrigation..... 287–289
Recent series, general features of..... 121–122
Rice culture, duty of water for..... 148–149
history of..... 144–145
outlook for..... 146
results of..... 145–146

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Page.
Rice culture, soils suitable for 147–148
source of water for 146–147
Rosebriar Prairie, deposits composing 114
situation of 29

S.

St. Francis County, geology of 263–264
physiography of 262–263
water resources of 264–267
wells in, data of 268–269
St. Francis River, course of 28
Salisbury, R. D., on the age of the Lafayette formation 98–99
See also Chamberlin, T. C.
Sand blows, nature of 29
Scale. *See* Boiler scale.
Searcy, section of the Lafayette formation south of 95–96
Shaw, E. Wesley, acknowledgment to 15
on the petrographic and mechanical characters of specimens of loess 103–104
Shepard, Edward M., record of well at Campbell, Mo., from 163
Shimek, Bohumil, on fossils in the loess 113
Sikeston Ridge, deposits composing 114
extent of 29
Softening of water, method of 295–296
Soil, accumulation of mineral matter in 287
Soils, Bureau of, mechanical analyses of loess by 104–105
Southland, log of well at 239
section of alluvium east of 118
Spencer Creek, section of the Claiborne formation on 68
Stabler, Herman, formulas of 284–285
Springs, use of 139
ratings of water for irrigation by 289
Strawberry, exposures of loess near 111
Streams, general features of 132–133
Stuttgart, wells at and near 151–152
"Sunk lands," nature of 160
Swamps, formation of 133

T.

Tabor, exposures of loess at 111
Tertiary formations, distribution and character of 44–100
ground water in 136–138
quality of 308
Tichnor, log of well near 153
Tilton, log of well northeast of 183
Trenton, section of alluvium southwest of 118
Triassic deposits, absence of 123
Troughs west and east of Crowleys Ridge, erosion of 129
Turrell, depth of well at 137
log of well at 175

U.

Ulm, log of well near 152

V.

Page.
Vanndale, log of well at 182
Vaughan, T. Wayland, direction by 14
fossils determined by 53–54, 78
Verdigris River, water of, analysis of 300

W.

Wabbaseka, log of well near 199
Waldenburg, logs of wells near 246
Walnut Ridge, logs of wells near 205
Waters, artesian, conditions governing occurrence of 140–141
artesian, definition of 140
ground, disposal of 135
pressure conditions of, in the Advance lowland 141–142
in the Mississippi lowland 142–143
quantity of 135
source of 134–135
uses of 143–149
mineral constituents of 281
nonartesian, development of 139–140
importance of 139
surface, quality of 134
See also Ground waters.
Weiner, logs of wells at and near 246, 247
Wells, Cretaceous strata penetrated in 42–43
which penetrate Pleistocene alluvium, references to 118–120
which penetrate undifferentiated Quaternary alluvium, reference to 122–123
waters from, analyses of 302
West Prairie, deposits composing 114
situation of 29
Wheatley, logs of wells near 265
White County, geology of 270–271
physiography of 270
water resources of 271–272
wells in, data of 273–274
White River, course and tributaries of 26
Whitehall, log of well near 247
Wilcox formation, correlation of 63
deposition of 125
general features of 54–57
local details of 57–63
sands, clays, and lignites of, plate showing 52
Wilson, well at 226
Wittsburg, section of the Lafayette formation north of 70
section of the loess north of 70
Woodruff County, geology of 275
physiography of 275
water resources of 276
wells in, data on 278–279
Wynne, sections of the Claiborne formation, east of 70–71
sections of the Lafayette formation east of 70–71, 92–93
sections of the loess east of 70, 71, 108–109
wells at 137, 181–182

Z.

Zent, logs of wells near 266–267

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